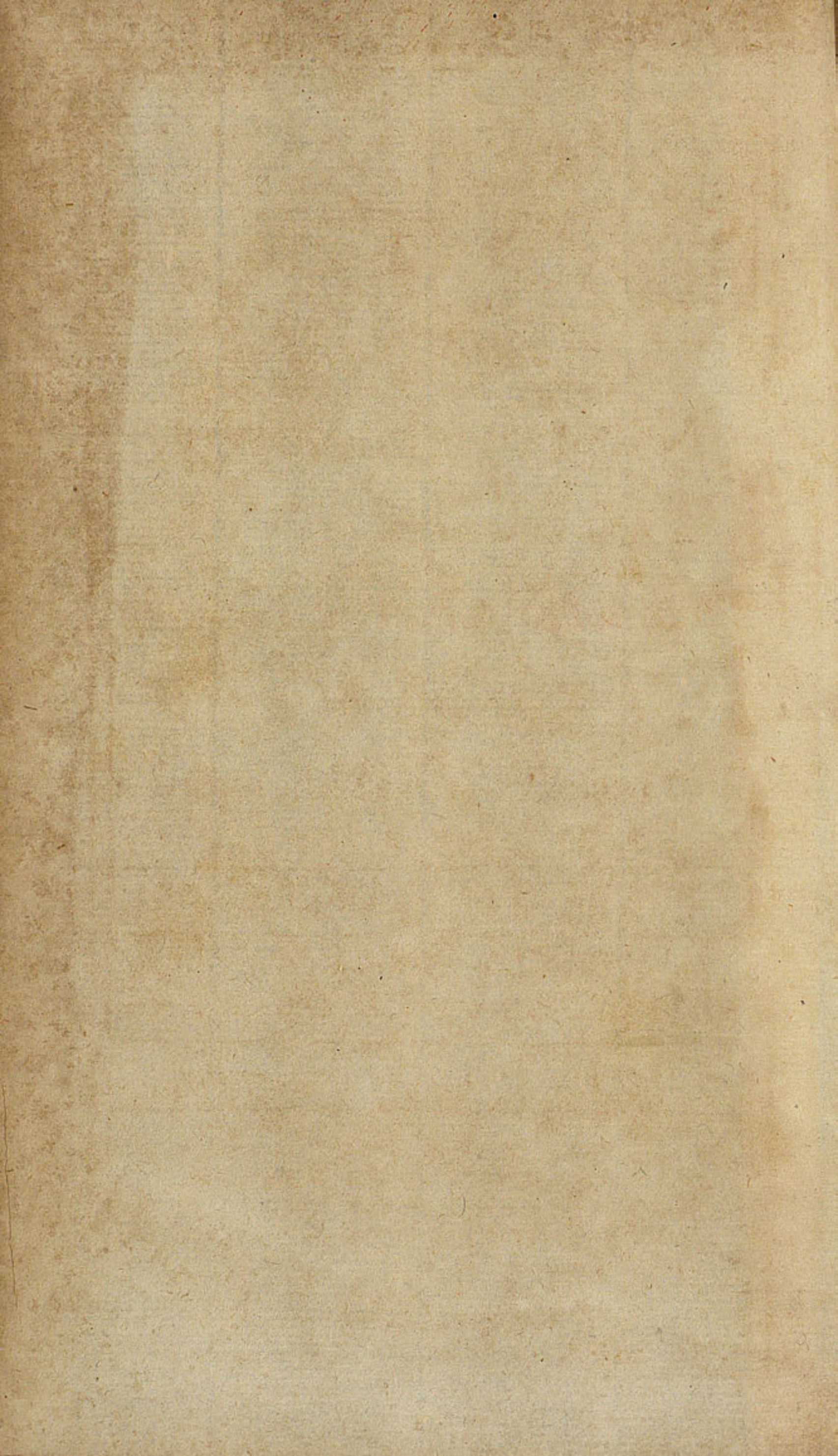

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ROHAULT's SYSTEM

OF

Natural Philosophy,

ILLUSTRATED WITH

Dr. *Samuel Clarke*'s NOTES

Taken mostly out of

Sir *Isaac Newton*'s Philosophy.

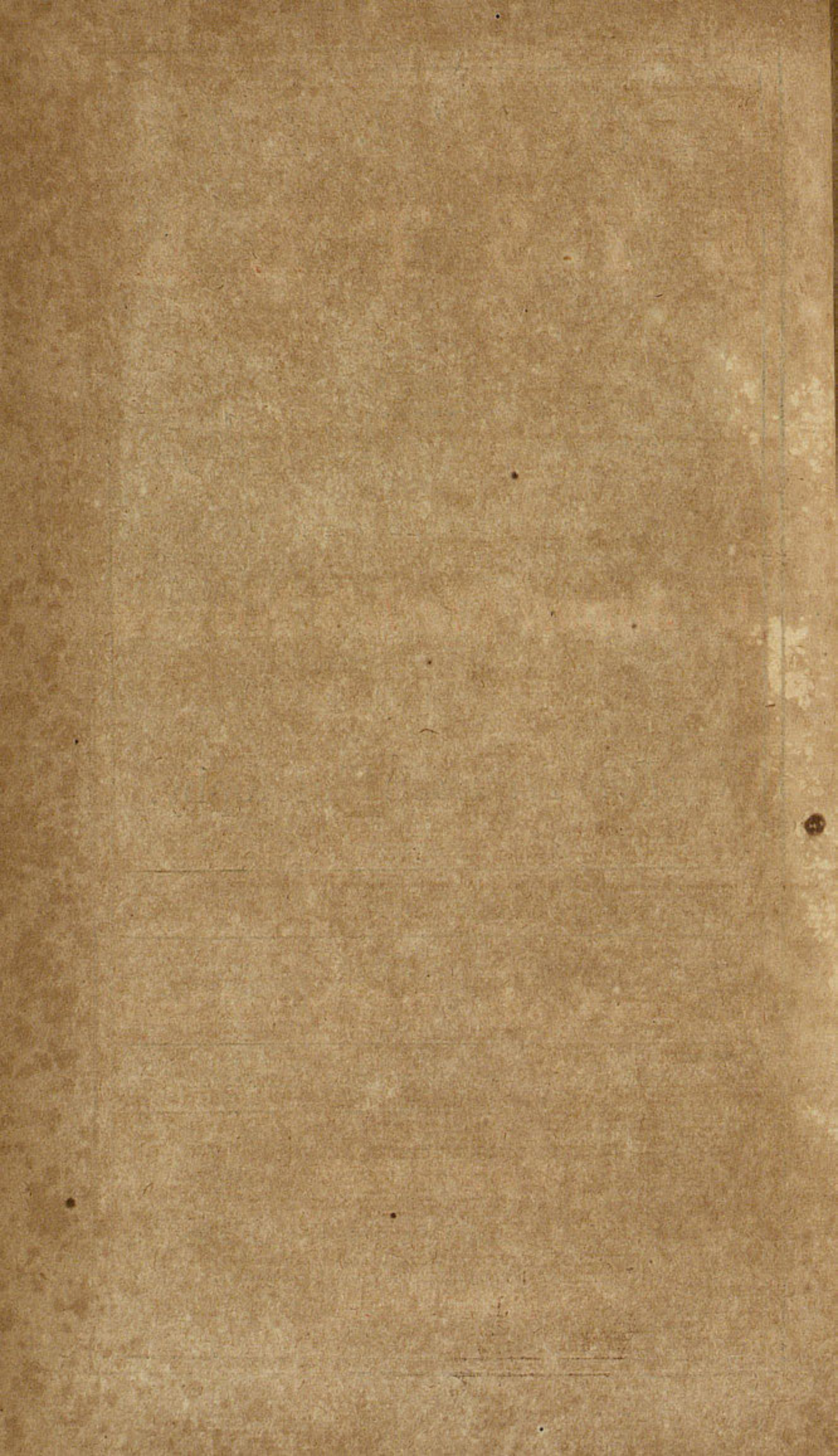
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PART II.

A DESCRIPTION OF THE WORLD.

CHAP. I.

Of the Meaning of the Word Cosmography, and the Usefulness of the Science.



HAT I now propose, is to give a general Idea of the World, that is, a Description of the Number, Situation, Magnitude, Figure, and some other Properties of the principal Parts of which the visible World is composed: And that Science which treats of these several Particulars, is called *Cosmography*.

1. What is meant by Cosmography.

2. This

2. The Usefulness thereof.

2. This Science is not only of great Use in itself, but also in the Consequences which follow from it. For beside that it is of great Advantage to us, to know the whole Structure of our own Habitation; we may also affirm, that there is such a Connexion betwixt the several Parts of the Universe, and they have such a Dependence upon, and are so linked with each other, that the greatest Part of those Events which are natural, and which affect us the nearest, cannot be explained without a perfect Knowledge of the particular Constitution of the World and of every Part of it, upon which they depend, as Effects do upon their Causes. This Science is also of great Use in *Geography*; because it is certain, that we cannot have a perfect Knowledge of the Situation of different Countries, with respect to each other, without having first settled the Place which the Earth is in, with regard to the other Parts of the Universe.

3. In what Manner it ought to be treated of.

3. Since the World is the Work, or rather the Diversion of the Hand of God, who could divide it into as many Parts as he pleased, and dispose them in an infinite variety of Ways; it is impossible for us to know the Number or Order of them, by any Reason drawn from the Nature of the Things themselves; and we can know only by Experience, which Way God was pleased to choose, out of those many in which they might have been disposed. We ought therefore to consider every Particular, as far as the Weakness of human Nature, assisted by all the Helps of Art and Industry, will permit, that we may go back, as far as we are able, from the Effects to the Causes; and first take Notice, how Things appear to us, before we make a Judgment of the Nature and Disposition of them.

CHAP. II.

General Observations.

1. That the Earth is finite, and of a certain Figure.

THE first Thing that we take Notice of, is the Earth which we inhabit, whose Superficies is interrupted and divided by a great Number of Rivers, Lakes, and Seas; and though the whole Bulk of Earth and Waters, seems to us to be immense, yet we are assured that it is bounded and limited, (for we know that a great many

Persons have gone round it different Ways) and consequently, that it is of a certain Figure.

2. This Figure must necessarily consist, either of a great many plain Superficies, or else of one particular Superficies; if it consists of but one continued Superficies, that must be a carved one. But the Earth cannot be bounded by a great many plain Superficies, because these would meet in different Angles where the Superficies are connected together, some of which we could not but take notice of; but we do not perceive any such Thing: On the contrary, where-ever we are, the whole Extent, as far as our Eye can reach, appears plain and level. We must conclude therefore, that the Earth is not terminated by a great many plain Superficies, but by one continued curved one. And further, because the Earth appears equally plain every where, we have no Reason to think, that the Superficies about it is of an unequal Curvature, and therefore we conclude it to be alike all over, that is the Earth and the Waters together are of [1] the Figure of a Sphere or a Globe, or a Ball, which is the same Thing.

2. That the Earth is round.

3. This Globe is every where surrounded with Air, beyond which is that immense Space which is called the Heavens, wherein we see a vast Number of Stars, amongst which we reckon the Sun and Moon.

3. Of the Air, the Heavens, and the Stars.

1 *The Figure of a Sphere*, &c.) Concerning the Earth's being round, See *Varenius*'s *Geography*, *Book* I. *Sect.* 2. and *Tacquet's Astronomy*, *Book* I. *Num.* 3. However it is certain that the Earth is not exactly and truly round, but its Diameter at the Equinoctial Circle is to its Diameter through the Poles, as 692 to 689. See *Newton's Princip. Book* III. *Prop.* 19.

But *Tacquet in his Astronomy*, *Book* I. *Chap.* ii. *Numb.* 6. *has* drawn some very neat Consequences from the Roundness of the Earth; which I shall add here.

First then. *If any Part of the Earth's Superficies be plain, Men can no more stand upright upon it, than they can upon the Side of a Mountain.* Secondly, *Because the Superficies of the Earth is globous, the Head of a Traveller goes a longer Journey than his Feet: And he who rides on Horseback, goes a longer Journey than he who walks the same Way on Foot: So likewise the upper part of the Mast of a Ship goes more Way than the lower*, viz. Because they move in Part of a larger Circle.

Thirdly. *If a man goes the whole Circumference of the Earth's Orb; the Journey which his Head travels exceeds that of his Feet, by the Circumference of a Circle, whose Radius is the Man's Height.*

Fourthly. *If a Vessel full of Water were lifted up perpendicularly, some of the Water would continually run over, and yet the Vessel would be always full*, viz. Because the Superficies of the Water would always be depressed into part of a larger Sphere.

Fifthly. *If a Vessel full of Water were carried directly downwards, though none of it ran over, yet the Vessel would not be full*, viz. Because the Superficies of the Water is raised continually into part of a less Sphere.

Whence it follows, Sixthly, *That the same Vessel will hold more Water at the Foot of a Mountain than at the Top; and more in a Cellar than in a Chamber.*

To which may be added. Lastly. *That two Threads upon which two Steel Balls hang perpendicularly, are not parallel to each other, but Parts of two Radius's which meet at the Center of the Earth.*

4. That there are fixed Stars and Planets.

4. The greatest Part of these Stars continue always in the same Place with respect to each other, which is the Reason why they are called *fixed Stars*; on the contrary, the other perpetually change their Place, and are therefore called wandring Stars or *Planets.*

5. Of the Number of the fixed Stars.

5. The Number of *the fixed Stars* which appear to the naked Eye, is a Thousand and Twenty Two, some of which have appeared but lately, and were unknown to the Antients; and They on the other hand saw some, which we cannot see now. There are also some Stars which appear but for a short Time, as that which was seen towards the latter end of the Year 1572, which at first appeared brighter and larger than any of the rest, but diminishing by Degrees, in about six Months it totally disappeared.

6. Of the Number of the Planets.

6. There are only seven Planets, the Names of which are, the *Sun*, the *Moon*, *Mercury*, *Venus*, *Mars*, *Jupiter* and *Saturn.*

7. What a Constellation is.

7. The Antients distinguished the whole of the fixed Stars into several *Signs* or *Constellations*, to which, without any other Reason than their own Fancies, they gave the Names of *Bear*, *Lion*, *Mermaid*, *Serpent*, &c.

8. That a great many more Stars may be seen by the help of a Telescope.

8. Besides the Thousand and Twenty Two fixed Stars now mentioned, innumerable others may be seen through a Telescope; and there may also be seen four little Planets which always accompany *Jupiter* at a small Distance from him, and [1] another little Planet always attending upon *Saturn.*

9. How the Planets may be known.

9. The *Sun* and *Moon* are the Principal amongst the Planets, and these are easily known: But the other Planets can be known only by their apparent irregular Motions, and by the Difference of their Light, which does not twinkle so much as that of the fixed Stars.

10. The apparent Motion of the whole Heavens.

10. All the Stars, as well the fixed, as the Planets, seem to us, to describe a great many Circumferences of parallel Circles, and to move from the East to the West.

11. What is meant by a natural Day.

11. They perform their Revolutions in pretty near equal Times; and the Time which the Sun takes up in going one Round, is called *a natural Day*, and is commonly divided into twenty-four *Hours*, and each Hour into sixty *Minutes.*

1 *Another little Planet*, &c.) Nay there may be seen with a good Telescope five small Planets moving about *Saturn*, as *Cassini* and *Hugenius* have observed.

CHAP. III.

Conjectures how to explain the apparent Motions of the Stars.

THESE Obſervations being allowed, there have been two Hypotheſes or Suppoſitions made, in order to account for them. The firſt is, that the Earth continues at Reſt in the Middle of the World, and that the whole Heavens move round it from Eaſt to Weſt, and carry all the Stars along with them.

1. The firſt Hypotheſis, That the Earth does not move.

2. The Second ſuppoſes on the contrary, that the Heavens and the Stars do not really move round in Four and Twenty Hours, as they appear to us to do; but that they are indeed at Reſt, and ſeem only to move; becauſe the whole Maſs compoſed of Earth, Water and Air, and of every Thing which we ſee here, does really turn round its own Center from Weſt to Eaſt.

2. The ſecond Hypotheſis, That the Heavens do not move.

3. The firſt of theſe two Hypotheſes or Suppoſitions was maintained by *Ariſtotle*, *Hipparchus*, *Ptolemy*, and a great many Philoſophers.

3. What Perſons were of the former Opinion.

4. The latter Hypotheſis was maintained by *Ecphantes*, *Seleucus*, *Ariſtarchus*, *Philolaus*, *Plato*, and the *Pythagoreans*. *Archimedes* alſo ſuppoſes this to be true, in his Book Entituled, *Of the Number of Grains of Sand.* This Opinion, after having been buried in Oblivion for many Ages, was reviv'd again by *Copernicus* about Two hundred Years ago.

4. Who were of the latter Opinion.

5. If we conſider theſe Two Hypotheſes, we ſhall find that they will both equally ſolve theſe Phænomena and general Obſervations; for all the viſible Parts of the Heavens will ſeem to turn round from Eaſt to Weſt in Twenty-four Hours, the ſame in one Hypotheſis as in the other. Wherefore having as yet no Reaſon to follow the one rather than the other, we ought to ſuſpend our Judgment with reſpect to each of them: But becauſe we have undertaken to argue from the particular Phænomena, which cannot be done without being of one Opinion, or taking Part with one Side, let us firſt ſuppoſe the common Opinion to be the true one.

5. That either of theſe Hypotheſes will anſwer the Phænomena.

CHAP. IV.

Of the Figure of the World.

Of the principal Points, Lines and Circles, which are imagined to be upon the Superficies of it.

1. By the former Hypothesis, the Heavens are limited and the visible World is of a spherical Figure.

WE cannot conceive any Body to be in Motion without comparing it with other Bodies, to which it is differerently applied. Now upon this Supposition, that the Heavens move, we must necessarily compare them with something that we imagine to be beyond them; and therefore we cannot but suppose them limited. And because Reason and Experience shew us, that a Body included within another, cannot move freely, if there be any Angles on its Superficies; therefore since the Heavens appear to move very freely, we do readily conceive their Superficies to be without any Angles, and consequently spherical; and further, not concerning our selves with what may be beyond this Superficies, but only taking all that is contained in it for the *Universe*, we affirm, that the World, or the Universe, is of a spherical Figure.

2. Of the diurnal Circles.

2. When we suppose the whole Heavens to turn round every Day, and to finish their Revolution in Twenty-four Hours, we imagine at the same Time, that every Point in them except Two, describe Circles parallel to each other, and these are called *diurnal* or *daily* Circles.

3. Of the Equator.

3. These Circles are all unequal, and the largest of them is called the *Equator*, or the *Equinoctial Circle*.

4. Of the Poles of the World.

4. The two Points in the Superficies of the Heavens which do not describe any Circles at all, but only turn about themselves, are called the *Poles of the World*. One of them, *viz.* that which is in the Part of the Heavens visible to us, is called the *Arctick Pole*, and the other the *Antarctick*.

5. Of the Axis of the World.

5. The streight Line which goes from one Pole to the other, and passes through the Center of the Earth, is called the *Axis* of the World.

6. Since

6. Since we can always ſee one Half of the Heavens, in what Part of the Earth ſoever we be, if our Sight be not hindred by Mountains, or ſome ſuch Thing, this is a Proof, that the Earth is but of a very inconſiderable Bigneſs, compared with the Heavens, and that it may be taken for a Point, with regard to the vaſt Extent of them.

6. That the Earth is very ſmall compared with the Heavens.

7. The Circle which ſeparates the viſible Part of the Heavens from that which is inviſible, is called the *Horizon*, which is different according to the different Parts of the Surface of the Earth where we are.

7. Of the Horizon.

8. The *Poles of the Horizon*, are two Points of the Superficies of the World, each of them equally diſtant from every Part of the Horizon; that Pole which is over our Head is called the *Zenith*, and the other the *Nadir*.

8. Of the Zenith and Nadir.

9. The *Meridian* is that Circle which we imagine to paſs through both the Poles of the World, and the Poles of the Horizon.

9. Of the Meridian.

10. It is evident, that the Meridian alters, if we go to any other Place, which is *Eaſt* or *Weſt*.

10. That the ſame Circle is not the Meridian every where.

11. The Circles which we conceive to paſs through the Poles of the World, and every Point of the Equator, are called *Circles of Declination*.

11. Of the Circles of Declination.

12. Thoſe Circles which we imagine to paſs through both Poles of the Horizon and every Point of its Circle, are called *Azimuths* or *vertical Circles, or Circles interſecting each other in the point directly over our heads.*

12. Of Azimuths.

13. Moſt part of theſe Things are by Analogy transferred to the Superficies of the Earth. Thus the *Earth's Equator*, or *Equinoctial Line*, or in general *the Line*, is a great Circle which we imagine to be on the Surface of the Earth directly under the Equator of the Heavens.

13. Of the Earth's Equator.

14. *The Axis of the Earth* is a Part of the Axis of the World, included in the Body of the Earth.

14. Of the Earth's Axis.

15. *The Poles of the Earth* are the two Extreme Points of its Axis.

15. Of the Poles of the Earth.

16. *The Meridians upon the Earth*, which are alſo called *Circles of Latitude*, are a great many Circles paſſing thro' the Poles of the Earth, and the ſeveral Points of the Equinoctial Line.

16 Of the Circles of Latitude upon the Earth.

17. There is one Meridian upon the Earth, which Geographers call the *firſt Meridian*, and *Ptolemy* has been uſually followed in this, who choſe for the firſt Meridian, the Circle that paſſes through the Iſland of *Hierro*, one of the Canary Iſlands.

17. Of the firſt Meridian.

18. The Order of the Meridians.

18. To know the Order and Number of Meridians, it is cuſtomary to reckon them from *Weſt* to *Eaſt*.

19. Of the Circles of Longitude upon the Earth.

19. *The Circles of Longitude upon the Earth*, are a great many Circles, which we conceive on its Superficies, to be parallel to its Equator: they are on both Sides of this Line, and diminiſh as they grow nearer to the Poles.

20. How any Circle is divided.

20. All the Circles which we imagine to be either in the Heavens or on the Earth, are divided into three Hundred and Sixty equal Parts, which are called *Degrees*, and every Degree is divided into Sixty Parts, which are called *Minutes*, &c. ſo that the Word *Minute* is ambiguous, ſignifying as well the Sixtieth Part of an Hour, as the Sixtieth Part of a Degree.

CHAP. V.

Of the chief Uſes of the Circles of the Sphere of the World.

1. The first Uſe of the Equator.

THE *Equator in the Heavens*, divides the World into two equal Parts; that in which the *Arctick* Pole is, is called the *Northern* Part, and the other is called the *Southern* Part.

2. Another Uſe of the Equator.

2. The Motion of the Equator is the Meaſure of Time, for we judge the time to be more or leſs, according as there paſs more or fewer *Degrees* of this Circle croſs the Meridian. The ſpace in which there paſſes fifteen Degrees of the *Equator*, is an Hour; and the Space in which there paſſes the Sixtieth Part of Fifteen Degrees, that is, fifteen Minutes, is a Minute of an Hour.

3. The First Uſe of the Horizon.

3. The *Horizon* divides the World into two equal Parts, which are called *Hemiſpheres*; that which is viſible to us, is called the *upper Hemiſphere*, and the other the *lower Hemiſphere*.

4. Another Uſe of the Horizon.

4. When the *Horizon* cuts any diurnal Circles, it is a Proof that thoſe Stars which are in theſe Circles riſe and ſet: on the other hand, when it does not cut any, it is an Argument that the Stars which are in theſe diurnal Circles, do not riſe and ſet at all.

5. When

5. When any of these Circles are cut by the Horizon, the upper part is called the *diurnal Arch*, and the lower Part the *nocturnal Arch*.

5. Of the diurnal and nocturnal Arches.

6. The Quantity of these Arches, shews us how long the Star which is in them, is above or below the *Horizon*.

6. The Use of these Arches.

7. The four Points where the *Meridian* and the *Equator* cut the *Horizon*, are called the *Cardinal Points*.

7. Of the Cardinal Points.

8. The Place where the *Meridian* cuts the *Horizon* in that Part where the *Arctick Pole* is, is called the *North*, and the Point opposite to it, is called the *South*.

8. Of the North and South.

9. The Place where the *Equator* cuts the *Horizon* on that Side where the Sun rises, is called the *East*, and the Place opposite to it, is called the *West*.

9. Of the East and West.

10. The Place which is between any two of those, has its Name from the Composition of those Two; thus the Place which is betwixt the North and the East, is called the * *North-East*, that which is betwixt the North and the West, is called the *North-West*; that which is betwixt the South and the East, is called the *South-East*, and that which is betwixt the South and the West, is called *South-West*.

10. Of the intermediate Points.

* See Vitruvius, *Book* I. *Chap.* vi.

11. The *Meridian* divides the World into two equal Parts, that which is on the Side where the Stars rise, is called the *East*, and the other the *West*.

11. The first Use of the Meridian.

12. The *Meridian* divides the diurnal Arches into two equal Parts, and therefore shews, that the Distance of the Stars from their rising to their coming to the Meridian, is equal to the Distance from the Meridian to their Setting.

12. Another Use of the Meridian.

13. The *Meridian* determines the greatest Altitude above the Horizon, of those Stars which rise and set; and both the greatest and the least Altitude of those Stars which never set.

13. A third Use of the Meridian.

14. The Arch of the Meridian contained betwixt the Pole of the World and the *Horizon*, is called the *Elevation of the* Pole, and so likewise the Arch of the Meridian contained between the Equator and the *Horizon*, is called the *Elevation of the* Equator.

14. Of the Elevation of the Pole and of the Equator.

15. Each of these two Elevations, is the Complement of the other to ninety *Degrees*, that is, either of them being taken out of ninety *Degrees*, the Remainder is the *other*.

15. Each of these is the Complement of the other to ninety Degrees.

16. *The Circles of Declination* serve to shew the Distance of any Star from the Equator; for what we call the *Declination*

16. The Use of the Circles of Declination.

Declination of a Star, is nothing elſe but an Arch of one of theſe Circles contained between the Star and the Equator.

17. The Uſe of the Azimuths.

17. The *Azimuths* ſerve to ſhew the Altitude or Elevation of a Star above the *Horizon*, or how far it is diſtant from this Circle.

18. Another Uſe of them.

18. The firſt *Azimuth* being that which cuts the *Meridian* at right Angles, and from whence we begin to number the reſt; it is evident, that if we know in what *Azimuth* any Star is, we can eaſily tell where to find it.

19. The Uſe of the terreſtrial Equator.

19. The *terreſtrial Equator* divides the Earth into two equal Parts, that in which the *Arctick* Pole of the World is, is called the *North*, and the other the *South*.

20. Another Uſe of it.

20. From this Circle we begin to reckon the *Latitude*, ſo that the Latitude of any Town or other Place of the Earth, is the Arch of a *terreſtrial Meridian* contained betwixt ſuch a Town or Place on the Earth and the *Equator*.

21. That the Latitude of any Place is equal to the Elevation of the Pole above the Horizon.

21. They who live in the terreſtrial Equator, have their *Zenith* in the celeſtial Equator, and they who live at any Number of Degrees diſtant from the terreſtrial Equator, have their *Zenith* as far removed from the celeſtial Equator; and becauſe there is always a quarter of a Circle contained between the *Zenith* and the *Horizon*, this latter Circle muſt neceſſarily be as far diſtant from the Pole, as the *Zenith* is from the celeſtial Equator: So that the Number of Degrees of the Elevation of the Pole above the *Horizon*, is always equal to the Number of the Degrees of the Latitude; wherefore if we know one of theſe, we know the other alſo.

22. How to find the Elevation of the Pole above the Horizon.

22. In order to find the Elevation of the Pole above the *Horizon*, we muſt obſerve the greateſt and leaſt Height of any Star which never ſets, and half the Difference of theſe two Heights, added to the leaſt, or taken from the greateſt, will give the Elevation of the Pole.

23. An Example.

23. Thus we obſerve at *Paris*, that the leaſt Height of the Star next to the Pole above the Horizon is 46 Degrees 25 Minutes, and its greateſt Height 51 Degrees, 25 Minutes. The Difference of theſe two Heights is 5 Degrees, the half of which is 2 Degrees 30 Minutes, which added to the leaſt, or taken from the greateſt Height, makes 48 Degrees 55 Minutes for the Elevation of the Pole, and conſequently this is the Latitude at *Paris*.

24. It

24. It is to be obſerved, that if a Star be at its leaſt Height above the *Horizon* at a given Hour, it muſt deſcribe half its diurnal Circle, before it come to its greateſt Height; and becauſe this will take up twelve Hours, it is evident, that the Star ought to be viſible all that Time, which ſhews, that ſuch Obſervations cannot be made but in the long Nights of the Winter.

24. That the foregoing Method of finding the Elevation is practicable only in Winter.

25. The Uſe of the *firſt Meridian*, is to cut every Circle of Longitude in a certain Point from whence we begin to reckon the Longitude of every other Point in that Circle. For what we call the *Longitude* of any Place upon the Earth, is nothing elſe but the Arch of any Circle of Longitude, contained betwixt the firſt Meridian and that Place, counting from *Weſt* to *Eaſt*: Thus we ſay, that the Longitude of *Paris* is 23 Degrees 30 Minutes; by which we mean, that the Arch of the Circle of Longitude which paſſes through *Paris*, and is contained between that City and the firſt Meridian, is 23 Degrees, 30 Minutes.

25. The Uſe of the firſt Meridian.

26. The *Circles of Latitude* and the *Circles of Longitude*, interſect and divide each other mutually. And indeed if we ſuppoſe, that there are three hundred and ſixty Semicircles of Latitude equally diſtant from each other, and one hundred and eighty Circles of Longitude equally diſtant from each other alſo, they will divide each other by their Interſections into *Degrees*; ſo that if any Town be upon the thirtieth Circle of Latitude, this ſhews it to have thirty *Degrees of Longitude*; and ſo likewiſe, if it be upon the fortieth Circle of Longitude, reckoning from the Equator to the Pole, this ſhews it to have forty *Degrees of Latitude*.

26. The Uſe of the Circles of Latitude.

27. Beſides theſe particular Uſes of the ſeveral Circles of the Sphere now mentioned, there is one which is common to them all, and which ought principally to be conſidered in this Place, and that is, that all of them together, do firſt help us to determine the *apparent Motion* of every Star, by which Means we come to the Knowledge of their *true Motions*. Let us firſt examine *that* of the Sun, the Properties of which ought to be enquired into before we conſider thoſe of the other Stars, as being moſt neceſſarily to be known.

27. The general Uſe of all the Circles.

CHAP.

CHAP. VI.

Observations about the Sun's Motion.

1. The first Phænomenon. THE Sun ſeems to us to deſcribe every Day from Eaſt to Weſt, a Circle parallel to the Equator.

2. The ſecond Phænomenon. 2. We obſerve, that the Sun does not deſcribe an exact Circle every Day ſucceſſively, for it does not riſe preciſely in the ſame Point of the Horizon any Day that it did the Day before.

3. The third Phænomenon. 3. The Sun ſo alters its Courſe, in paſſing croſs the *Horizon* and *Meridian*, as to make a great many Revolutions in the Northern and a great many in the Southern Parts of the World.

4. The fourth Phænomenon. 4. There are certain Limits in the *Horizon* and in the *Meridian*, which the Sun never paſſes; theſe Limits in the *Meridian*, are *twenty three Degrees and a Half* diſtant from the Equator on each Side.

5. The fifth Phænomenon. 5. When the Sun riſes near either of theſe Limits, the Place of its riſing, and alſo that where it croſſes the Meridian, is leſs ſenſibly altered, than when it is near the Equator.

6. The ſixth Phænomenon. 6. The Sun moves ſlower from Eaſt to Weſt than the fixed Stars, as is eaſy to be obſerved; for if at any Time we ſee a Star in the Meridian two or three Hours after the Sun is ſet, and look upon the ſame Star a Month after at the ſame Hour from Sun ſet, the Star will be got thirty Degrees diſtant from the Meridian.

7. The ſeventh Phænomenon. 7. The Sun appears bigger in the Southern Part than in the Northern.

8. The eighth Phænomenon. 8. The Sun makes ſeven or eight Revolutions more in the Northern than in the Southern Part.

CHAP. VII.

Conjectures how to explain the Phænomena of the SUN.

LET us imagine in the Sphere of the World, a Circle, whose Position is such, that cutting the cæleſtial Equator in two Points diametrically oppoſite to each other, it makes with it an Angle of twenty three Degrees and a half: This Circle we ſhall henceforth call the *Ecliptick*.

1. Of the Circle called the Ecliptick.

2. Let us imagine further, that the Sun is ſo carried from Eaſt to Weſt by the common Motion of the whole Heavens, that whilſt it goes once round in this manner, the Place of the Heavens in which it is contained (and which may be called its own particular Heaven) carries it from Weſt to Eaſt in the Plane of the Ecliptick, in which it advances near a Degree every Day, in a Circle whoſe Circumference is not every where equally diſtant from the Earth, but is a little nearer it in the Southern Part of the World, than in the Northern.

2. Of the Sun's proper Motion.

3. This Circle, whoſe Center is different from the Center of the Earth, is called the *Sun's excentric Orbit*: That Point of it, which is at the greateſt Diſtance from the Earth, is called the *Apogæum*, and that Point which is neareſt, is called the *Perigæum*.

3. Of the Sun's excentrick Orbit, and of its Apogæum and Perigæum.

4. By means of this Hypotheſis, of which *Hipparchus* was the Inventor about one hundred and twenty Years before the Birth of our Saviour; not only all Phænomena which we juſt now mentioned, may be accounted for, but all thoſe likewiſe, which may be here or elſewhere obſerved.

4. This is Hipparchus's *Hypotheſis, and ſolves all the Phænomena.*

5. And *firſt*, Becauſe the whole Heavens move round from Eaſt to Weſt, it is evident, that the Sun muſt likewiſe move round in the ſame manner, and deſcribe a Circle parallel to the Equator.

5. Why the Sun ſeems to move from Eaſt to Weſt.

6. *Secondly*, Becauſe the Sun goes forward near a *Degree* in the Ecliptick every Day, it muſt change its Declination every Day, that is, its Diſtance from the Equator; and conſequently it muſt riſe every Day in a different Place, and never croſs the Horizon two Days together in the ſame Point.

6. Why it riſes in different Places in the Horizon.

7. *Thirdly*,

7. Why it describes Circles, both in the Northern and Southern Parts.

7. *Thirdly*, The *Ecliptick* extending itſelf both into the Northern and Southern Part of the World; the Sun in paſſing through all the Degrees of it, muſt neceſſarily make a great many Revolutions on each Side of the Equator.

8. Why there are certain Bounds in which the Sun riſes.

8. *Fourthly*, And becauſe it never moves out of the *Ecliptick*, it can never be further diſtant from the Equator, than the Ecliptick itſelf is; therefore there are certain Limits both in the *Horizon* and *Meridian*, beyond which it never paſſes.

9. Why the Sun does not alter its Places of Riſing and Setting every Day equally alike.

9. *Fifthly*, As the poſition of the Circumference of the Ecliptick in the Heavens now is, the extreme Parts of the ſame Degree are not ſo unequally diſtant from the Equator, in thoſe Places of the Ecliptick which are furtheſt from it, as in thoſe Places where theſe Circles interſect each other. Wherefore the Sun ought not ſo ſenſibly to alter its Diſtance from the Equator every Twenty-four Hours, when it is near thoſe Points where the Ecliptick and Equinoctial Circle are at the greateſt Diſtance, as when it is near where they interſect; and conſequently it muſt at that Time leſs ſenſibly alter its Place of Riſing and Setting and croſſing the Meridian every Day.

10. Why the Sun moves ſlower from Eaſt to Weſt, than the fixed Stars do.

10. *Sixthly*, The Motion of the Sun, from Eaſt to Weſt, ought to be ſo much ſlower than that of the fixed Stars, as it advances every Day towards the Eaſt.

11. Why the Sun appears ſometimes bigger than at other Times.

11. *Seventhly*, The Sun being nearer the Earth when it is in the Southern Part, than when it is in the Northern, it ought to appear bigger in the one than it does in the other.

12. Why the Sun deſcribes more Revolutions in the Northern than in the Southern Parts.

12. *Eighthly*, Becauſe there is a greater Part of the Sun's *Excentrick Orbit* contained between the Equator and the Arctick Pole, than between the ſame Equator and the Antarctick Pole, therefore the Sun has more *Degrees* to paſs through, and conſequently more Revolutions to make in the Northern, than in the Southern Parts of the World.

13. Why the Days are not all of an equal Length.

13. Now if we look upon an Artificial Sphere, which repreſents the natural Globe of the World, we ſhall ſee that amongſt all the diurnal Circles which the Sun deſcribes every Day, it is the Equator only which is cut into two equal Parts by the *Horizon*, and that thoſe Circles which are on the Northern Part of the World, have the Diurnal Arch bigger than the Nocturnal, and thoſe on the Southern Part, have on the contrary, the Nocturnal Arch bigger than the Diurnal; hence it neceſſarily fol-

follows, that when the Sun is in the Equator, the Days and Nights muſt be equal, when the Sun is in the Northern Parts, the Days muſt be longer than the Nights, when it is in the Southern Parts, the Nights muſt be longer than the Days.

14. Which is the longeſt and ſhorteſt Day.

14. We ſhall alſo ſee that the Difference betwixt the diurnal and nocturnal Arch of one and the ſame Circle, is ſo much the greater as the Circle is further diſtant from the Equator; whence it follows, that the longeſt Day muſt be, when the Sun is at its greateſt Diſtance that it can be from the Equator on that Side where the viſible Pole is; and on the contrary, the ſhorteſt Day muſt be when it is furtheſt diſtant towards the inviſible Pole.

15. That the Days and Nights are always equal to them who live under the Equator.

15. If we place the two Poles of the artificial Sphere in the *Horizon*, in order to repreſent the Situation of the natural Globe, with reſpect to thoſe People who live in the Equinoctial Circle, we ſhall ſee that all the diurnal Circles are divided into two equal Parts; and therefore to thoſe People the Days are always equal to the Nights.

16. The further we are removed from the Equator, the longer are the Days.

16. We may obſerve alſo, that the further any Place is diſtant from the Equinoctial Line, and conſequently the higher the Elevation of the Pole be, ſo much the greater alſo will the diurnal Arches be than the Nocturnal, on that Side where the Pole is elevated: Whence it follows, that when the Sun deſcribes theſe Arches, the Days ought to be longer than the Nights in proportion to the Diſtance from the Equinoctial Line.

17. That there is one Day, Twenty-four Hours long, where the Latitude of the Place is 66 Degrees 30 Minutes.

17. The diurnal Circle, which the Sun deſcribes when it is at the greateſt Diſtance from the Equator towards the viſible Pole, being diſtant from the Equator 23 *Degrees* and 30 *Minutes*, it follows, that it is diſtant from the Pole of the World 66 *Degrees* and 30 *Minutes*. This being ſo, thoſe People who are in the Latitude of 66 *Degrees* and 30 *Minutes*, which is the heighth of the Pole to them above the Horizon, muſt neceſſarily ſee this whole diurnal Circle; whence it follows, that they have one Day Twenty-four Hours long.

18. That thoſe who live under the Poles have a Day and a Night of ſix Months each.

18. By elevating the Pole of the artificial Sphere above the Horizon to the Zenith, ſo as to repreſent the Situation of the natural Globe, with regard to thoſe People who live upon the Pole of the Earth; we ſhall find the cœleſtial Equator to coincide with the Horizon; and therefore, ſo long as the Sun is in that Part of the World, where the Pole is elevated, it will be always

visible to that People, that is, it will be Day all that Time; and on the other Hand, as the Sun will be invisible as long as it continues in the other Part of the World, it follows, that their Night will be very near as long as their Day was.

19. *What the Zodaick is.*

19. We imagine the Ecliptick, as we do all the other Circles of the Sphere, not to have any Breadth; but we take a Breadth of six Degrees on each Side of the Ecliptick to compose a Breadth of twelve Degrees, to which we give the Name of *Zodiack*; so that we may say, the Sun is always in the Middle of the *Zodiack.*

20. *Of the twelve Signs.*

20. This Circle is commonly divided into twelve equal Parts, which are called the *Twelve Signs*, the order of which is reckoned from West to East, beginning at the Point where the Equator and Ecliptick intersect each other, and where the Sun by its proper Motion passes from the Southern to the Northern Parts of the World.

21. *Of the Names of the Signs.*

21. The Names which the Antients thought fit to give to the Signs, are, *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpio*, *Sagittarius*, *Capricornus*, *Aquarius*, and *Pisces.*

22. *Whence these Names were borrowed.*

22. These Names are taken from the twelve Constellations which were in these Signs in *Hipparchus*'s Time; but they have changed their Places so much since, that the Constellation called *Aries*, is got out of the Sign *Aries* into that of *Taurus*, and so of the rest.

23. *Of the Equinoctial Points.*

23. There are four remarkable Points in the Ecliptick, two of which are in those Places where the Ecliptick and Equator intersect each other, which are called the *Equinoctial Points* in particular, because when the Sun is in these Points, it is the Equinox, that is, the Days and Nights are equal.

24. *Of the Solstices.*

24. The other two Points are in those Places which are furthest distant from the Equator, and are called the *Solstices*, that is, the Points where the Sun seems to stand still; not that when it is got thither, it does not move as usual, either with that Motion which it has in common with the Heavens from East to West, or with its own proper Motion in its Heaven from West to East; but because it does not seem to advance either towards the North or the South.

25. *Of the two Tropicks.*

25. When the Heavens turn round in twenty-four Hours, the Solstitial Points describe two Circles parallel to the Equator, which are called the *Tropicks*; that is called the *Tropick of Cancer*, which is described by the first Point of the Sign *Cancer*; and that is called the *Tropick of*

Capricorn, which is described by the first Point of the Sign *Capricorn.*

26. As the Ecliptick is *Twenty-three Degrees and a half* distant from the Equator, so are the Poles of the Ecliptick as far distant from the Poles of the World: Whence it follows that by the diurnal Motion of the Heavens, the Poles of the Ecliptick must describe Circles parallel to the Equator, which are *Twenty-three Degrees and a half* distant from the Poles of the World, and these are called the *Polar Circles.*

26. Of the Polar Circles.

27. If we transfer the two *Tropicks*, and the two *Polar* Circles to the Surface of the Earth, it will be divided into five Parts which are called the five *Zones*; that which is contained between the two *Tropicks*, is called the *Torrid Zone*; those which are contained between the *Tropicks* and the *Polar* Circles, are called the *Temperate Zones*; and the two remaining ones, each of which are comprehended in a *Polar Circle*, are called the *Frigid Zones.*

27. Of the Zones.

28. The Time in which the Sun goes through the whole Ecliptick, is called a *Year*, and is 365 Days, 5 Hours and about 49 Minutes.

28. Of a Year, and the length of it.

29. That this Year might obtain all over the *Roman* Empire, and that the 5 Hours and 49 Minutes which the common Year consists of above 365 Days, might make the least Error that could be; *Julius Cæsar* appointed, that for the future, every fourth Year should consist of 366 Days; by this means the Year would not be above eleven *Minutes*, or thereabouts, longer than it should be; which was thought to be an inconsiderable Error.

29. Of the Julian *Year, and that it is not exact.*

30. However, this Error so increased by little and little in length of Time; that whereas in the Times of the first *Christians*, the Sun entered into *Aries* not till the twenty-first Day of *March*, fifteen hundred Years after, it entered the eleventh, which is ten Days difference: And this was the Reason of Pope *Gregory* the XIII's ordaining, that this Error of ten Days should be taken out of the Year 1582, so that instead of consisting of 365 Days, it should consist only of 355: And because in length of Time the same Error would happen again, if there were no regulation made, he appointed, that in the first Year of every Century, except every four hundredth Year, the intercalated Day should be left out.

30. Of the Gregorian *Emendation.*

31. Why the Dates of Letters written by different Nations the ſame Day, do not always agree.

31. As the *Engliſh* and ſome other Nations have not received this Alteration, ſo they differ ten Days in the Dates of their Letters. Thus when we reckon it the twenty-fifth of *January*, they reckon it but the fifteenth.

32. Of the Spring.

32. The Time which the Sun takes up in paſſing through the Signs, *Aries*, *Taurus*, and *Gemini*, is called the *firſt Seaſon* of the Year, or the *Spring*; and as the Sun is found to be in the firſt Point of *Aries*, about the twenty-firſt Day of *March*; the *Spring* begins upon that Day.

33. Of the Summer.

33. The Time in which the Sun paſſes through the three following Signs, *viz. Cancer*, *Leo*, and *Virgo*, is called the *Summer*; and begins about the twenty-firſt of *June*.

34. Of the Autumn.

34. The Time in which the Sun paſſes through the Signs, *Libra*, *Scorpio*, and *Sagittarius*, is called the *Autumn*, which begins about the twenty-third of *September*.

35. Of the Winter.

35. And the Time which the Sun paſſes through the Signs *Capricorn*, *Aquarius*, and *Piſces*, is called Winter, and begins about the twenty-firſt of *December*.

36. The falſity of the common Reaſon alledged for its being hotter in Summer than in Winter.

36. We find it hotter when the Sun is near the Summer than when it is near the Winter Solſtice; which has been hitherto attempted to be explained, by ſaying, that the Rays of the Sun fall leſs oblique upon the Surface of the Earth in the Summer than in the Winter. But this Opinion appears very improbable, if we conſider that the Superficies of the Earth is not ſmooth like a Looking-Glaſs, but very rough and unequal, ſo that the Rays fall perpendicular upon as many Places in Winter as in Summer.

37. The true Reaſon why it is hotter in Summer than in Wintr.

37. We may with more Probability ſay, that the Superficies of the Air in which we live, when it is at the Height of about two or three *Leagues*, where there is never any Winds or Clouds, is perfectly ſmooth and even, like all other Liquors which are not in Motion; and as it is the Property of the Rays of Light when they are about paſſing out of one *Medium* into another, not to enter all of them, [1] but to be reflected in a greater Number,

1 *But to be reflected in a greater Number*) To this we may add, that the more oblique the Rays fall, beſides their being hindered by Reflection, the thinner they fall, even from the very Nature of Obliquity both upon the Atmoſphere, and upon the Surface of the Earth. Thus the Rays BC

ber, as they fall more obliquely; it follows, that there muſt come a greater Number of Rays to us, when the Sun is near the Summer, than when it is near the Winter Solſtice. And from this greater Number of Rays which come to us at that Time, ariſes the Heat which we feel in Summer.

38. The near-er any Place is to the Equinoctial Line, the hot-ter it is.

38. Hence we may conclude, that the nearer the Sun approaches the Zenith of any Place, the hotter it is: Thus, becauſe it approaches nearer the Zenith at *Rome*, than at *Paris*, therefore we find it is hotter at *Rome* than at *Paris*.

39. That it is hotteſt of all under the Line.

39. We may conclude alſo, that it is hotter under the Equinoctial Line, than in any other Part of the Earth; as well becauſe the Sun paſſes twice in a Year through the Zenith of thoſe who live there, as becauſe it is never ſo far diſtant from their Zenith, as from that of others.

40. Particular Cauſes, that may make ſome Alteration in the general Cauſe.

40. However, it may ſo happen, that Experience may ſeem to contradict this Argument; for there may be, in ſome Places, particular Cauſes which may augment or diminiſh the general Cauſe. The particular Cauſes are theſe three; the Winds, the Quality of the Earth, and the Situation of it. For, *Firſt*, It is certain, that the Winds which blow from the Sea to the Land, muſt very much abate the Heat. *Secondly*, The more ſandy the Earth is, the fewer of the Sun's Rays does it abſorb; and conſequently, beſides the Heat which they cauſe by falling directly, they muſt alſo increaſe the Heat of the Air by being reflected. *Laſtly*, The lower any Place is (provided the Sun comes as much to it) the groſſer and thicker is the Air, which therefore cauſes us to feel the Heat more.

41. How to find the Sun's Declination every Day.

41. When the Sun's Motion is once eſtabliſhed according to the Rules of Geometry, it is very eaſie to make Tables which ſhall ſhew in what Point of the Ecliptick the Sun is every Day: There are alſo Tables which contain the Declination of every Point of the Ecliptick, ſo that we can know exactly the Declination of the Sun every Day at Noon.

B C when they fall perpendicularly, are all of them received by the Superficies S G; but when the ſame Rays M O fall oblique, they take up a larger Superficies D H, and therefore cauſe leſs Heat becauſe they are thinner. (Tab. XVII. Fig. 4.)

42. How to find the Latitude of any Place where we are.

42. Hence we may eaſily find the Latitude of the Place where we are any Day of the Year, provided the Air be clear. For we need only take the Meridian Altitude of the Sun with an Inſtrument, that is, its greateſt Altitude that Day; then if the Sun be in that Part of the World whoſe Pole is inviſible, add its Declination to the Meridian Altitude, or if it be in that Part of the World whoſe Pole is viſible, ſubduct this Declination from the Meridian Altitude, and the Sum or Difference will be the Altitude of the Equator, the Complement of which to 90 *Degrees* is the Elevation of the Pole, which is equal to the Latitude ſought.

43. Of the Climates, and how to find the Number of them.

43. [1] Hence we may alſo find what the Latitude of any Place muſt be, that the longeſt Day of Summer may be of a given Length: Whence we may determine the Bigneſs of every *Climate*: For by the Word *Climate*, we mean, *a Tract of the Earth comprehended betwixt two Circles parallel to the Equator, at ſuch a Diſtance from each other, that there is half an Hour's Difference between the longeſt Day of Summer in the one, and the longeſt Day of Summer in the other.*

44. That there are twenty-four Climates between the Equator and each Polar Circle.

44. The further we go from the Equinoctial, [2] the more the longeſt Day increaſes, till we come to the Polar Circle, where the longeſt Day is twenty-four Hours; that

1 *Hence we may alſo find*, &c.) The greateſt Declination of the Sun being given. For when the Sun riſes in the *Tropick*, we may imagine *a right-angled ſpharical Triangle* compoſed of the Complement of the forementioned Declination as the Baſe, and the ſought Altitude of the Pole, and the Arch of the *Horizon* contained between the Sun and the Point where the *Meridian* cuts the *Horizon* in the Northern Parts as the Sides. Now in this Triangle the Baſe is given, and the acute Angle at the Pole is alſo given, by means of the adjoining obtuſe Angle, *viz.* half the given Length of the Day, converted into Degrees, in the Equinoctial Line; from whence may be found the Altitude of the Pole ſought. So likewiſe the Length of the longeſt Day may be found, if the Altitude of the Pole be given. But if we would know the Length of the continual Days in thoſe Places which are within the Polar Circles, *viz.* in the *Monthly Climates* (See *Art.* 45. *of this Chap.*) we muſt take the Altitude of the Pole out of ninety Degrees, and the Remainder will be the Declination of the Beginning of that Arch in the Ecliptick which is always elevated above the *Horizon*; twice the Diſtance of which, beginning from the Beginning of *Cancer*, will make the whole Arch that is always viſible; How long the Sun is moving through this Arch, muſt be had by computing his true Motion from the *Aſtronomical Tables*. By the ſame Method on the contrary, from the given Length of the continual Day, may be found the Altitude of the Pole in any of theſe *Monthly Climates*.

2 *The more the longeſt Day increaſes*, &c.) Not only the longer, but the more unequally longer alſo, as is evident from the following *Article*. In order therefore to explain this great Inequality of the Climates, let us ſuppoſe a great many *oblique Horizons* to be made by receding with en equable Motion from that which is called the *right Horizon*; it is evident, that all theſe *Horizons* by their

that is, twelve Hours, or twenty-four half Hours longer than under the Equator: Whence it follows, that there muſt be twenty-four Climates, betwixt the Equinoctial and the Polar Circle; and becauſe the longeſt Day at *Paris* is ſixteen Hours, that is, eight half Hours longer than under the Equinoctial Line; therefore *Paris* is ſituate in the End of the eighth, or the beginning of the ninth Climate.

45. How to determine the Climates beyond the Polar Circle.

45. When we go beyond the Polar Circle towards the Pole, we ſhall find a very great Increaſe of the longeſt Day of Summer; wherefore in thoſe Places, we mean by the Word Climate, a Tract of Land, comprehended between two Circles parallel to the Equator, at ſuch a Diſtance from each other, that there is a Month's Difference between the longeſt Day of Summer in the one, and the longeſt Day of Summer in the other. Now becauſe at the Pole it ſelf, it is continual Day for ſix Months, therefore there are ſix Climates betwixt the Polar Circle and the Pole.

46. Why the Antients did not reckon ſo many Climates as the Moderns.

46. As many Climates as there are betwixt the Equinoctial Line and one of the Poles, ſo many ought we to imagine betwixt the ſame Line and the other Pole; whence it follows, that there are ſixty Climates in all. This does not indeed agree with the Writings of the Antients, who did not reckon near ſo many, but the Difference ariſes from hence; that they confined the Word Climate to the habitable Parts of the Earth; and becauſe the Zones towards the Antarctick Pole were unknown to them and eſteemed inhabitable, as well as the torrid Zone, and the Northern frigid Zone, therefore they reckoned but a very few Climates.

their Interſections with the Semicircle of the *Tropick* that is elevating, will form *Chords* diſtant from each other by ſuch unequal Arches, that thoſe of them which are formed by the moſt oblique *Horizons*, are a great deal further diſtant from each other, than thoſe of them which are formed by the leaſt oblique *Horizons*; much after the ſame manner, as the Arches contained between the Extremes of two *Chords* at ſome Diſtance from the Diameter of any Circle, are greater than thoſe between two *Chords* at the ſame Diſtance from each other, which are nearer the Diameter. By the ſame Similitude, may that other Inequality of the *Monthly Climates* be explained, if we imagine diurnal Circles to form *Chords* in the ſame manner, by their Interſections with the Ecliptick. For it will appear, that two ſuch *Chords* that are near the *Tropick*, contain bigger Arches of the Ecliptick between their Extremes, than two at the ſame Diſtance from each other which are nearer the Equator; and the diurnal Circles which are near the *Tropick*, may be conceived to be much thicker and cloſer than thoſe near the Equator, and therefore there is no need of receding ſo much from a *right Sphere*, in order to make thirty of the thickeſt of them riſe entirely above the *Horizon*, as to make ſo many of thoſe which are not ſo thick, riſe.

47. That the Sun's Apogæum *is altered, and his Excentricity diminished.*

47. That we may not omit any Thing relating to the Sun, we must take notice, that his *Apogæum* has altered its Place in the Heavens; for at the Time of our Saviour, it was in the Eighteenth Degree of *Gemini*, and now it is in about the Eighth Decree of *Cancer*. It is observed also, that the Distance between the Center of the Earth, and the Center of the Sun's excentrick Orbit, which is called his *Excentricity*, is not so great as it was formerly; so that the Sun is not so far distant from us in Summer as it was, but a little further distant in Winter.

48. That these Alterations are very irregular.

48. The Progress of the *Apogæum*, and the Diminution of the *Excentricity*, are not according to any Rules, and of all the *Hypotheses* hitherto made, there have been none that would entirely agree with the Observations made by Astronomers at different Times.

CHAP. VIII.

Observations and Conjectures about the fixed Stars.

1. Whence it is that Astronomers have not all agreed about the Motion of the fixed Stars.

BECAUSE it will take up a great many Ages to observe the *Phænomena* of the fixed Stars; and because late observers have taken notice of many Particulars, which escaped those who went before; therefore there have been very different Conjectures made from time to time about their Motions.

2. Hippar-*chus thought that the fixed Stars moved only from East to West.*

2. *Hipparchus* lived the greatest Part of his Life, without observing any Thing more of the fixed Stars, but that they moved from East to West in Circles which appeared exactly parallel to the Equator: which made him conclude, that they were all placed in the same solid Heaven (*which is called the Firmament*) which he supposed to be[1] beyond all the Planets; and because he did not see any Necessity that this Heaven should derive its Motion, which is a simple one, from any other Heaven above it; he therefore affirmed this to be the last of the Heavens, and that it turned all the others

1 *Beyond all the Planets*, &c.) Concerning the Distance of the fixed Stars. See *the Notes on Chap.* XXV. *Art.* 3. *of this Part.*

round

round along with it, and therefore is the *Primum Mobile*.

3. It being then the Opinion of *Hipparchus*, that the fixed Stars never altered their Places in the Heavens, he thought they would be of ufe to determine the Courfes of the Planets; in the fame manner as Rocks in the Sea are made ufe of to obferve the Courfe of Ships which leave no Tract behind them: He therefore imployed all his Pains, to meafure the Diftance of every fixed Star from the Ecliptick, which is called the Stars *Latitude*; and to find out how many Degrees and Minutes of the Ecliptick, reckoning from Weft to Eaft, there were between the firft Point of the Sign *Aries*, to the Point directly againft every fixed Star; which is called its *Longitude*: But he being prevented by Death, it was left to Pofterity to finifh what he defigned.

3. How he determined the Longitude and Latitude of the fixed Stars.

4. *Ptolemy*, who lived about two hundred Years after *Hipparchus*, propofed to eftablifh the Motion of the Planets; and having the Curiofity to obferve whether his Predeceffor had been exact in determining the Longitude and Latitude of the fixed Stars; he obferved, that their Latitude was exactly the fame as *Hipparchus* found it, but that their Longitude was increafed two Degrees.

4. The apparent Motion of the fixed Stars from Weft to Eaft obferved by Ptolemy.

5. From hence he concluded, that befides the Motion of the fixed Stars from Eaft to Weft in twenty-four Hours, they had another Motion from Weft to Eaft in Circles parallel to the Ecliptick, in which having advanced two Degrees in two hundred Years, their periodical Revolution would be compleated in thirty-fix thoufand Years,

5. The Periodical Time of this Motion.

6. And becaufe the Firmament can have but one Motion only belonging to it, he afcribed this Motion of Thirty-fix thoufand Years to this; and made the diurnal Motion from Eaft to Weft, to depend upon another Heaven which is beyond it: And thus the *Primum Mobile*, as a Heaven in which there were no fixed Stars, and which included the Firmament in it, began to be received.

6. How a Primum Mobile *came to be eftablifhed, diftinct from the Firmament.*

7. The *Aftronomers* who have been fince *Hipparchus*, have acknowledged the Motion of the fixed Stars from Weft to Eaft, which is increafed fo much, that the Longitude of every fixed Star is become about 28 Degrees more than it was in our Saviour's Time; but becaufe this Progrefs hath been unequal in different Centuries, there have been different periodical Times affigned. Some have affirmed, that it takes up forty-nine thoufand Years to

7. That the Progrefs of the fixed Stars from Eaft to Weft is irregular.

to compleat an entire Revolution of them, others but twenty-five thoufand, and others ftill different: But later *Aftronomers*, who had the Advantage of the Obfervations of others, have declared the Motions of the fixed Stars to be irregular, and that it is impoffible precifely to determine the Time of their Revolution.

8. How the Chryftalline Heaven came to be eftablifhed.

8. Becaufe this Opinion did not agree with the Followers of *Ariftotle*, who affirm, that the Heavens cannot be fubject to any Alteration; therefore it feemed more probable to fome, that the Firmament it felf moved exactly regularly, and that every Irregularity was to be afcribed to fome external Caufe: Wherefore they imagined a certain Heaven to be betwixt the Firmament and the *Primum Mobile*, which by its own proper Motion, librated fometimes from Eaft to Weft, and fometimes from Weft to Eaft, and by that means accelerated and retarded the apparent Motion of the fixed Stars by Turns. This was called the *Chryftalline* Heaven.

9. Of the Alteration of the Declination of the Ecliptick, and the eftablifhing a fecond Chryftalline Heaven.

9. It is to be obferved further, that the Ecliptick, which is now twenty-three Degrees and a half diftant from the Equator, was diftant from it twenty-three Degrees and fifty-two Minutes in *Ptolemy*'s Time: In order to account for this Alteration, they imagined another Chryftalline Heaven ftill, which they made to librate from North to South, and from South to North.

10. That Aftronomers need only to confider the diurnal Motion of the fixed Stars.

10. Whatever the Progrefs of the Firmament be, whether regular or irregular, fince there is no fenfible Difference during a Man's Life, it is fufficient for any Aftronomer to obferve once in his Life, the Longitude and Latitude of the fixed Stars, in order thereby to determine the Motion of the Planets.

CHAP.

CHAP. IX.

Obſervations about the MOON.

IF we make the like Obſervations about the Moon that we have done about the Sun, we ſhall find that their Phænomena are pretty much the ſame. For firſt we obſerve, that it moves round the Earth every Day from Eaſt to Weſt in a Circle which ſeems parallel to the Equator,

1. The firſt Obſervation about the Moon.

2. But by daily Obſervation we find, that it is not an exact Circle which it deſcribes, becauſe it alters its Places of Riſing and Setting every Day; and that ſo ſenſibly, that this Alteration is as much in one ſingle Day, as that of the Sun is in thirteen or fourteen Days.

2. The ſecond Obſervation.

3. There are Limits in the *Horizon* and Meridian, beyond which the Moon never paſſes, and they are very near the ſame with thoſe of the Sun.

3. The third Obſervation.

4. The Moon moves ſlower from Eaſt to Weſt than the fixed Stars, as may eaſily be obſerved in one Night.

4. The fourth Obſervation.

5. The following Conjecture is built upon theſe Obſervations, *viz.* that whilſt the Moon is carried from Eaſt to Weſt by the *Primum Mobile*, it has alſo a proper Motion of its own from Weſt to Eaſt in a Circle which cuts the Equator, and declines very near as much from it towards the Poles, as the Ecliptick does; but whether this Circle of the Moon be the ſame as the Ecliptick or different from it, cannot be determined by the Eye.

5. That theſe Obſervations are not ſufficient to determine the Moon's proper Motion.

6. We muſt therefore have recourſe to the Method propoſed by *Hipparchus*, viz. to meaſure every Day the Diſtance betwixt the Moon and two fixed Stars, [1] whoſe Longitude and Latitude are known, in order to find the Londitude and Latitude of the Moon every Day: Hereby we ſhall ſee that the Moon advances every Day about thirteen *Degrees* and a *half* from Weſt to Eaſt, in a Circle which cuts the Ecliptick, and deviates from it about five Degrees on each Side, ſo that it goes through

6. How to find out the Moon's proper Motion.

1. *Whoſe Longitude and Latitude are known,* &c.) See *Mercator's Aſtron.* pag. 202.

the

the whole Circle in twenty-seven Days and a half, or thereabouts.

7. Of the Periodical and Synodical Months.

7. This Time is what we call the Moon's *Periodical Month*, and ought not to be confounded with another Sort of Month which is called *Synodical*, and which consists of twenty-nine Days and a half, which the Moon takes up from the Time that it is in the same Degree of the Zodiack with the Sun, to the Time that it meets with it again in another Degree thereof.

8. What the Conjunction of the Sun and Moon, or what the New Moon is.

8. When the Sun and Moon meet together in the same Degree of the Zodiack, it is called *a Conjunction of the Sun and Moon*, or, *the New Moon.*

9. What the Quadrature or Quarter of the Moon is.

9. When the Sun and Moon are ninety *Degrees* distant from each other, it is called the *Quadrature*, or *Quarter of the Moon*, which happens twice every Month.

10. Of the Opposition or Full Moon.

10. When the Sun and Moon are a hundred and Eighty *Degrees* distant from each other, it is called the *Opposition*, or *Full Moon.*

11. Of the Moon's Appearance near the Conjunction.

11. At the Time of the Conjunction the Moon cannot be seen at all; but one or two Days after, it appears *horned*, and the *Horns* are always turned towards that Part of the Heavens which is opposite to the Sun.

12. How it appears at the Opposition.

12. These Horns increase as the Moon gets further from the Sun, and it appears *full* and *intirely round*, when it is in its Opposition.

13. That the Moon's Diameter does not appear always the same.

13. The Diameter of the Moon does not appear to be [1] always the same, for we observe it to be least at the Times of the Quadratures, and to be biggest at the Time of its Opposition, and about the Time of its Conjunction.

14. That its apparent Motion from West to East is unequal.

14. The Motion of the Moon from West to East, is sensibly quicker at the Time of its Opposition and Conjunction, than at the Time of its Quadratures.

15. That the Course of the Moon is not always the same.

15. The Circle in which the Moon seems to move from West to East is not always the same; it describes a new one every Month, and crosses the Ecliptick in different Points successively from East to West.

16. Of the Dragon's Head, and Dragon's Tail.

16. That Intersection of the Ecliptick and the Moon's Circle, where the Moon passes from the Southern Part of the World to the Northern Part (with respect to the Ecliptick) is called the *Dragon's-Head*, or the *ascending Node*, and the other Intersection is called the *Dragon's-Tail*, or the *descending Node.*

1 *Always the same* &c.) See *the Notes on Chap.* 22. *Art.* 5. *of this Part.*

17. If

17. If we obferve the Dragon's-Head in any Point in the Ecliptick, it will be about nineteen Years before it be in that Point again.

17. That the Dragon's Head changes its Place.

18. To thefe *Phænomena* we may add, that we frequently obferve the Moon to pafs betwixt us and fome of the Stats, but never any Star to pafs between the Moon and us.

18. That the Stars are often hid by the Interpofition of the Moon.

19. Thefe are all the *Phænomena* which Aftronomers have laboured to find out the Reafons of: but natural Philofophers have long fince obferved further, that a little after the Moon's Conjunction, not only the Horns of it are to be feen, but all the reft of its Surface which is towards us appears of an Afh-Colour.

19. Of the faint Light which the Moon fometimes reflects.

CHAP. X.

Conjectures whereby to explain the Phænomena of the MOON.

IN order to folve thefe *Phænomena*, *Ptolemy* fuppofed the Moon's Heaven to be neareft the Earth.

1. The firft Hypothefis of Ptolemy.

2. *Secondly*, That this Heaven, whilft it is carried every Day from Eaft to Weft by the *Primum Mobile*, is, by its own proper Motion, advanced thirteen *Degrees* and a *half* about the Poles of the Zodiack.

2. The fecond Hypothefis.

3. *Thirdly*, That the Moon is not placed exactly in its own Heaven, but in the Circumference of a large round Body (called an *Epicycle*) included in its Heaven like a Diamond in a Ring.

3. Of the Moon's Epicycle.

4. *Fourthly*, That the lower Part of this Epicycle in which the Moon is fix'd, turns from Weft to Eaft, and the upper Part from Eaft to Weft, in fuch a manner, that the fmall Circle which the Moon by this means defcribes, is always in the Plain of the great Circle, in which it is carried about the Earth in twenty-feven Days and a half.

4. Of the Motion of this Epicycle.

5. *Fifthly*, This *Epicycle* turns about its own Center in fuch a manner, that when the Moon is in Conjunction with, or Oppofition to the Sun, [1] it is in the lower Part

5. How long time a Revolution of this Epicycle takes up.

1. *It is in the lower Part of its Epicycle, &c.)* See the *Notes on Chap.* xxii. *Art.* 5. *of this Part.*

of the *Epicycle* or in its *Perigæum*; and when the Moon is in its Quadratures it is in the upper Part of the *Epicycle* or in its *Apogæum*; that is, the *Degrees* which the Moon moves in its Epicycle are double the Number of thoſe the *Epicycle* moves in departing from the Sun.

6. That the Moon receives its Light from the Sun.

6. *Laſtly*, *Ptolemy* was of the ſame Opinion with *Thales* the *Mileſian*, that the Moon is a dark ſpherical Body, and receives all that Light by which we ſee it from the Sun.

7. Upon theſe Suppoſitions, all the foregoing Phænomena may be ſolved.

7. Theſe *Hypotheſes* being allowed, the foregoing *Phænomena* of the Moon, which are very near the ſame as thoſe of the Sun, may eaſily be ſolved.

8. Why the Moon appears to move from Weſt to Eaſt.

8. Further, it is manifeſt, that they explain why the Moon appears to deſcribe a Circle from Weſt to Eaſt in the *Zodiack*; becauſe it is ſuppoſed really to deſcribe ſuch a Circle.

9. Why this Motion is quicker at the Times of the Conjunction and Oppoſition.

9. Moreover, becauſe at the Times of Conjunction and Oppoſition, the Moon is ſuppoſed to be in the lower Part of its *Epicycle*, and that when it is in that Part, it is carried from Weſt to Eaſt; this Motion conſpiring with the Motion of its Heaven, which carries the whole *Epicycle* the ſame Way; it neceſſarily follows, that the Moon muſt then appear to move with great Swiftneſs towards the Eaſt, and becauſe it is then nearer the Earth alſo,[1] it muſt appear very large.

10. Why it is ſlower at the Times of the Quadratures.

10. On the contrary; becauſe at the Times of the Quadratures, the Moon is ſuppoſed to be in the upper Part of its *Epicycle*, and that when it is in that Part, it is carried from Eaſt to Weſt; the Space in which it is thus moved by its *Epicycle*, muſt be deducted from that Space in which it is carried by its Heaven from Weſt to Eaſt, ſo that it advances but the Difference only of them; and therefore its apparent Progreſs from Weſt to Eaſt, ought to ſeem leſs than at any other Time of its Revolution; and becauſe its Diſtance from the Earth is then increaſed, by the Length of the Diameter of its *Epicycle* it muſt appear leſs.

11. Why the Moon cannot be ſeen at all, at the Time of its Conjunction.

11. Becauſe the Moon has no Light at all of its own, but borrows that by which we ſee it, from the Sun; it is evident, that it ought not to be ſeen at all at the Time of its Conjunction, becauſe then the upper Part, which is enlightned, is turned from us, and the lower Part, which is not enlightned, is turned towards us.

1 *It muſt appear very large*) See the Notes on Chap. xxii. Art. 5. of this Part.

12. As the Moon gets further from the Sun, either towards the Eaſt or towards the Weſt, it ought to appear *horned*, becauſe a Part only of the inlightned Half is turned towards the Earth; and its *Horns* ought to appear turned towards that Part of the Heavens which is oppoſite to the Sun, becauſe the Light is bounded on that Side.

12. Of the Horns of the Moon.

13. At the Time of the Oppoſition, the whole lower Part of the Moon is turned toward the Sun, and towards us, and therefore it muſt appear *full*.

13. Why it appears intirely round at the Oppoſition.

14. Becauſe the Moon's Heaven is ſuppoſed to be the neareſt to the Earth, it follows, that the Moon may ſometimes paſs betwixt us and ſome of the Stars; but no Star can paſs betwixt that and us; which is agreeable to Experience.

14. Why ſome Stars are hid ſometimes by the Interpoſition of the Moon.

15. As to that faint Light which we perceive in the Moon's Body when it is near the Conjunction; *Galilæus* is the firſt, that I know of, that thought it to be cauſed by the Rays of the Sun, reflected thither by the Earth, which is proved by the following Arguments. Firſt, The Earth is an opake Body, and therefore it muſt neceſſarily reflect ſome Part of the Light which falls upon it. Secondly, becauſe this faint Light cannot be ſeen but when the Moon is very nearly right againſt the Middle of that half of the Earth which is enlightned by the Sun. Laſtly, Becauſe this Light of the Moon is ſenſibly greater, when, Riſing in the Eaſt, the Rays which reflect a great deal of Light from the Continent of *Aſia* fall thicker upon it, than when Setting in the Weſt, the Rays only which are reflected from the Ocean, which abſorbs moſt of them, fall upon it.

15. Whence that faint Light which appears on the Part of the Moon turn'd from the Sun.

CHAP. XI.

Of ECLIPSES.

WHEN the Moon paſſes between the Sun and the Earth, and hinders us from ſeeing it; this is called an Eclipſe of the Sun, which is ſo much the greater, the more the Sun's Body is covered; and it may be total, if it be intirely darkned by the Moon's Interpoſition.

1. What an Eclipſe of the Sun is.

2. It

2. Why there are but few total Eclipses of the Sun.

2. It is but very ſeldom, that there happens a total Eclipſe of the Sun, becauſe the apparent Diameter of the Moon is very ſeldom bigger than the apparent Diameter of the Sun, but is commonly ſomewhat leſs.

3. That different Parts of the Earth don't ſee the Sun equally eclipſed at the ſame Time.

3. Becauſe the Earth is of a conſiderable Bigneſs, compared with the ſmall Diſtance that the Moon is from it, it may happen, that the Moon may paſs betwixt the Sun and ſome particular Countries, and not paſs betwixt the Sun and ſome other Countries at all; whence it follows, that with reſpect to ſome People the Sun may be very much eclipſed, and not at all eclipſed with reſpect to others.

4. That there can be an Eclipſe of the Sun, at New Moon only, and that not always.

4. It is evident, that there can be no Eclipſe of the Sun, but when the Moon is New, or in Conjunction with the Sun, and not then, unleſs the Moon in its Motion from Weſt to Eaſt be exactly in the Ecliptick; but becauſe the Circle which it deſcribes, is at ſome Diſtance from the Ecliptick there are a great many Conjunctions without any Eclipſe at all, nor indeed can there be any but when the Moon is near the Dragon's-Head or Tail.

5. That the Darkneſs cauſed by a total Eclipſe of the Sun, continues but a ſhort time.

5. The Motion of the Moon from Weſt to Eaſt being very quick, it gets from under the Sun in a very ſhort Time when it is eclipſed, ſo that it is eclipſed but a little while; and when the Eclipſe is total, the Darkneſs can continue but a few Minutes, becauſe we ſhall immediately have ſome Light from that Part of the Sun which begins to be uncovered.

6. What an Eclipſe of the Moon is.

6. It may happen, that when the Moon is in Oppoſition to the Sun, it may be in the Dragon's Head, or Tail, or very near one of them; and if it is ſo, it ought not to be ſeen at all, [1] becauſe the Earth ſhades it, and hinders the Sun's Light from falling upon it, which is that which makes it viſible. This Deficiency of Light, or this Shade in which the Moon is, is called *an Eclipſe of the Moon*, which is *partial* and not *total*, if the Moon be ſo far diſtant from the Nodes, that it is not intirely immerſed in the Earth's Shadow.

1 *Becauſe the Earth ſhades it, &c.*) *Tacquet in his Aſtronomy, Book 4. Chap.* ii. *Numb.* 17. has demonſtrated, that the Shadow of the Earth never reaches ſo far as the Moon, ſo that the Moon is darkned not by the Shadow of the Earth, but by that of the Earth's Atmoſphere only; which was obſerved, though not ſo exactly demonſtrated by *Kepler* and *Riccilus*.

7. When

7. When at the Time of the Oppoſition, the Moon is at a Diſtance from its Nodes; becauſe it has then a good deal of Latitude, it does not enter at all into the Earth's Shadow, and hence it is, that there is not always an Eclipſe every full Moon.

7. Why there is not an Eclipſe of the Moon at every Oppoſition.

8. When the Moon enters in, or comes out of the Shadow of the Earth, that Part which is eclipſed always appears in the Form of a Circle; and becauſe Obſervations have been made of a great Number of Eclipſes, in which the Moon has entered in, and come out of the Shadows in all Parts of it, and the Appearance hath been always the ſame, it follows, that the Shadow of the Earth is round.

8. That the Shadow of the Earth is round.

9. And becauſe theſe Obſervations have been made when the Moon hath been oppoſite to different Parts of the Earth; this is a Confirmation of what was before aſſerted, *viz.* that the Earth is round every Way.

9. That the Earth it ſelf is round every Way.

10. When the Moon paſſes through the Middle of the Shadow, it continues eclipſed for a conſiderable Time, *viz.* Two or three Hours, which ſhews that the Diameter of the Moon is much leſs than that of the Earth's Shadow.

10. That the Diameter of the Moon is leſs than that of the Shadow of the Earth.

11. Further, when there is an Eclipſe of the Moon, the nearer the Moon is to the Earth, the longer the Eclipſe continues; whence we collect, that the Shadow is larger nearer the Earth than at a further Diſtance, ſo that it diminiſhes in proportion to its Diſtance like a Cone.

11. That the Shadow of the Earth diminiſhes like a Cone.

12. Becauſe the Moon is leſs than the Shadow of the Earth, and this Shadow decreaſes like a Cone, it follows, that the Moon is leſs than the Earth.

12. That the Moon is leſs than the Earth.

13. And becauſe the Shadow of the Earth could not decreaſe in this manner, if the Body which enlightens it were not bigger than itſelf; therefore we conclude, that the Sun is bigger than the Earth.

13. That the Sun is bigger than the Earth.

14. Becauſe that Part of the Moon which enters into the Shadow really loſes its Light, all thoſe People to whom the Moon is viſible, when it begins to be eclipſed, muſt ſee it at the ſame Time, and take notice of the Gap that it makes upon the round Face of the Moon; ſo that if all Nations had any particular Thing in view, and agreed to do it at the ſame Moment of Time; ſuppoſe it were to find exactly *what it is a Clock*, or any other Thing, the Beginning of an Eclipſe of the Moon would ſerve for a Signal.

14. That all thoſe People who can ſee the Moon eclipſed at all, ſee it at the ſame Time.

15. To find out how far any one Place of the Earth is East of another.

15. If different People, who at the ſame Moment of Time had obſerved ſeparately *what a Clock it was* at the ſeveral Places where they were, afterwards communicated their Obſervations to each other, or gave them all to one Perſon; it is eaſy to collect, that all they who obſerved it to be *the ſame Hour* at the ſame Moment of Time, live on the Earth under the ſame Meridian; and becauſe it is ſooner Noon-day the more Eaſt any Place is, we are therefore aſſured, that if it is ſooner Noon-day in one Place, than in another, that Place is Eaſt of the other; and becauſe the diurnal Motion of the Sun is fifteen *Degrees* in an Hour, we from hence conclude, that one Place is ſo many *fifteen Degrees* Eaſt of another, as it is *Hours* ſooner than the other.

16. Of the Longitude upon the Earth.

16. The Number of *Degrees* that one Place of the Earth is more Eaſt than another, is called the *Difference of Longitude*; and as the Knowledge of this is of very great Importance, it is worth while to illuſtrate it by an Example. Suppoſe, That at the Beginning of an Eclipſe of the Moon, it were by Obſervation, Eleven Hours and Thirty-four Minutes after Noon; and that we had Notice from the *Iſland of Fer* (one of the *Canary* Iſles) that it was Ten Hours after Noon there at the ſame Moment of Time; the Difference of theſe two Obſervations, is an Hour and Thirty-four Minutes, which ſhews, that the Difference of Londitude, betwixt theſe Places, is Twenty three Degrees, and thirty Minutes: Wherefore if we ſuppoſe the firſt Meridian to paſs thro' the Iſland of *Fer*, this Difference ſhews us the true Longitude of *Paris*.

17. That it is difficult to find the Longitude.

17. Becauſe Eclipſes of the Moon happen but ſeldom, and the Air is not always clear when they do happen; it is therefore but ſeldom that the Longitude can be obſerved from them.

18. The Foundation of Geography.

18. The Longitude and Latitude of the ſeveral Places upon the Earth being known, their Situation upon the Globe is thereby determined; ſo that the Rules upon which this Knowledge is built, are the principal Foundations upon which the Whole of Geography depends.

19. The Foundation of the Art of Navigation.

19. Navigation, or the Art of Sailing, conſiſting chiefly in determining exactly from Time to Time, the Place where we are upon the Sea (which cannot be accurately done but by the Longitude and Latitude) the Method of finding out both theſe, is the principal Foundation of Navigation.

CHAP. XII

Of the true Bigneſs of the Earth, Moon, and Sun, and of their Diſtance from each other.

1. A Method of finding how much the Circumference of the Earth is.

WHAT was juſt now ſaid, being throughly underſtood, it affords us an eaſy Method of finding how much the Circumference of the Earth, and how much its Diameter is, how far the Moon is diſtant from it, the Bigneſs of the Moon compared with the Earth, the Diſtance betwixt the Earth and the Sun, and how much the Sun's Diameter is. To determine then *the Circumference of the Earth*, we need only to take two Towns of the ſame Longitude, that is, which are under the ſame Meridian, and to obſerve the Difference of their Latitude, that is, the Number of *Degrees* and *Minutes*, counted upon the Earth's Meridian, contained between the two Towns, for this is the Difference; after which, if we know how many Leagues there are betwixt one Town and the other, it is eaſy to find how many Leagues there are in a *Degree*, whence it is eaſy to compute how many Leagues there are in three hundred and ſixty *Degrees* upon the Earth.

2. An Example.

2. For Example, Suppoſe *Paris* and *Amiens* were the two Towns fixed upon; they have both the ſame Longitude, becauſe they are under the ſame Meridian: Further, the Latitude of *Paris* is *Forty-Eight Degrees* and *fifty five Seconds*, and the Latitude of *Amiens* is *forty-nine Degrees* and *fifty-five Seconds*, and therefore the Arch of the Meridian contained betwixt *Paris* and *Amiens* is one Degree. But it is reckoned to be twenty-eight Leagues from *Paris* to *Amiens*, or more truly, twenty-five Leagues, allowing the three Leagues for the winding of the Road, and then a Degree upon the Meridian of the Earth will be twenty-five Leagues, and conſequently three hundred and ſixty Degrees, which is the whole Circumference of the Earth, will be nine thouſand Leagues.

3. Of the Earth's Semi-diameter.

3. Now the Circumference of any Circle is to its Diameter, as twenty-two to ſeven; the Circumference of the Earth therefore being nine thouſand Leagues, its Diameter muſt be about two thouſand eight hundred and ſixty-three; whence it follows, that the Di-

ſtance from the Circumference to the Center of the Earth, is very nearly one thouſand four hundred and thirty-one Leagues.

4. How to find the Diſtance betwixt the Earth, and the Moon; and what the Parallax is.

4. In order to find out the Diſtance betwixt the Center of the Earth and the Moon, we muſt ſuppoſe its Motion to be eſtabliſhed with ſuch geometrical Exactneſs, that its Place in the *Zodiack* may be known for any Day; and alſo its Altitude above the *Rational Horizon*, the Plane of which we imagine to paſs through the Center of the Earth: After this, we muſt obſerve in the Place where we are, the Altitude of the Moon above the *ſenſible Horizon*, which we ſuppoſe to be parallel to the *rational Horizon*; then the Difference betwixt theſe two Altitudes, is equal to the Angle contained between two viſual Rays, or two ſtreight Lines, going from the Center of the Earth, and the Place where we are, and meeting in the Center of the Moon; now this Angle (which is called the *Pallax*) being given, it is eaſy by by Calculation, to find the Diſtance betwixt the Center of the Earth and the Moon.

5. An Example.
Tab. XII. Fig. 1.

5. This will be better underſtood by the following Figure, where the ſmall Circle repreſents the Earth, whoſe Center is D; A is the Place of the Obſervator's Foot, CDE the *rational Horizon*, and the Line FG repreſents the *common or ſenſible Horizon*, on the Plane whereof ſtands the Obſervator, being parallel to the *rational Horizon*; the great Circle is the Meridian, in which the Moon is in the Place B; its Altitude above the *rational Horizon* is the Angle BDE, and its Altitude above the Surface FG is the Angle BAG; the Difference betwixt theſe two Angles, is the Angle ABD, which is called the Parallax, [1] which being known, we can find the Line DB, which is the Diſtance from the Center of the Earth to the Moon; as alſo the Line AB, which is the Diſtance of the Obſervator from the Moon: After this, by meaſuring the Angle under which the Moon appears, that is the Angle contained betwixt the Rays which come from the extreme Parts of the Moon, which is called its *apparent Diameter*, we can find alſo its *true Diameter*.

1 *Which being known, &c.*) For the Angle BAD (which exceeds the Angle BAG by ninety Degrees) and the Angle B, with one of the Sides AD being given, the Sides AB and DB are found by the common Rules of Trigonometry. Tab. XII. Fig. 1.

6. By exact Calculation upon these Observations, we find that the greatest Distance of the Center of the Earth from the Moon is [1] somewhat more than sixty-six Semi-diameters of the Earth, and its least Distance about fifty-one; and that the Moon's *true Diameter* is pretty near a fourth Part of that of the Earth, whence we conclude, that the Earth is about forty-five Times as big as the Moon.

6. How much the Distance betwixt the Earth and the Moon is, and how big the one is compared with the other.

7. The further any Star is distant from the Earth, and the higher it is above the *Horizon*, the less is its * *Parallax*; that of the Sun is not sensible, unless when it is in the *Horizon*, that is, in the Circle which terminates our Sight: And when the Sun is in the *Horizon*, it is very difficult to find its *Parallax*. Upon the most exact Calculation, its greatest Distance from the Earth is found to be [2] about fifteen hundred and fifty Semi-diameters of the Earth, and its least Distance about fourteen hundred and forty-six Semi-diameters. The Diameter of the Sun is also found to be about fifteen Semi diameters of the Earth; whence it follows, that the Sun is about four hundred and thirty-four times as big as the Earth.

7. What the Distance of the Earth from the Sun is, and what the Sun's true Bigness is.

** That is, the Angle ABD is so much less, as is evident to any one that considers the Figure.*

1. *Somewhat more than*, &c.) Astronomers are pretty well agreed about the Moon's Distance from the Earth: Its mean Distance, is, according to *Tycho*, fifty-six Semi-diameters and a half of the Earth, according to *Copernicus*, Sixty and one Third, and according to most others, fifty nine.

2. *About Fifteen hundred and fifty*, &c.) As it is very difficult and troublesome to find the Sun's Parallax, so its Distance from the Earth is not so well agreed upon. The Sun's mean Distance is by some reckon'd 749 Diameters of the Earth, by others 10000 or 12000, but by the exactest Observations of the latest Astronomers, but 5000; and its true Diameter to the Diameter of the Earth, as 10000 to 208. Whence it follows, that the Sun is many Thousand times bigger than the Earth.

According to the best Astronomers, the true Bigness of the Planets and their Distance from the Sun are as follows,



The Diameter of		
The Sun is	494100	Miles
Saturn	43925	
Jupiter	52542	
Mars	2816	
The Earth	8202	
The Moon	2223	
Venus	4941	
Mercury	2717	

	mean Distance from the Sun is	
Saturn's	513540000	Miles
Jupiter's	280582000	
Mars's	82242000	
The Earth's	54000000	
Venus's	39096000	
Mercury's	20952000	

Concerning the Distance of the fixed Stars, See *the Notes on Chap.* XXV. *Art.* 3. *of this Part.*

CHAP. XIII.

Of the Phænomena of Mercury *and* Venus.

1. How to know Mercury.

THE Planet *Mercury* is very ſmall, and they only who find it out by the Rules of Aſtronomy, can know it and diſtinguiſh it from the fixed Stars; it is ſo bright, as to be eaſily taken for a fixed Star.

2. How to know Venus.

2. Next to the Sun and Moon, the Planet *Venus* is the moſt remarkable, becauſe it appears ſo large; all Country-men almoſt, know it by the Name of the *Shepherd's-Star*.

3. Of the apparent Motions of Mercury *and* Venus.

3. By comparing *Mercury* and *Venus* with the fixed Stars according to *Hipparchus*'s Method, in order to know what the Poſition of their Orbits is, with regard to the Ecliptick; we find, that each of theſe Planets moves from Weſt to Eaſt in Circles, which cut the Ecliptick in two oppoſite Points, and deviate from it to a determinate Diſtance, *viz.* that of *Mercury*, ſix *Degrees* and ſixteen *Minutes*, and that of *Venus*, three *Degrees* and thirty *Minutes*.

4. Of the periodical Times of Mercury *and* Venus.

4. *Mercury* and *Venus*, take up about a Year in moving round their Orbits; and though they ſeem ſometimes to move faſter, they recompenſe it by moving ſlower at other Times, without obſerving any Rule; yet however, they perform their Revolutions in ſuch a manner, as always to paſs through their Orbits in a Year; ſo that we may affirm in general, that they make one Revolution every Year.

5. Of the Diſtances of Mercury *and* Venus *from the Sun.*

5. *Mercury* and *Venus* appear always very near the Sun: *Mercury* is never above twenty-eight *Degrees*, and *Venus* never above forty-eight *Degrees* diſtant either to the Eaſt or Weſt.

6. And how long Time they are in moving to theſe Diſtances.

6. When *Mercury* and *Venus* are the moſt Eaſt that they can be, of the Sun; that is, when *Mercury* is twenty-eight *Degrees*, and *Venus* forty-eight Eaſt of it; We obſerve, that they then move ſlowly towards the Weſt, till they are got as far Weſt of the Sun as they were before Eaſt of it: After this they ſeem to return back again to the Eaſt, and overtake the Sun, till they are got as much Eaſt of it, as they were at firſt; this is performed by *Mercury* in ſix Months, and by *Venus* in nineteen Months.

7. *Mercury* and *Venus* are ſometimes hid by the Interpoſition of the Moon; and theſe Planets are ſometimes ſeen to paſs betwixt the Sun and us.

7. That Mercury *and* Venus *appear ſometimes between the Sun and us.*

CHAP. XIV.

Conjectures for explaining the Phænomena of Mercury *and* Venus.

PTOLEMY thought that *Mercury* and *Venus* had each of them a Heaven belonging to them, and theſe he placed between the Moon and the Sun; and he imagined *Mercury*'s Heaven to be neareſt the Earth, and *Venus*'s to be further of.

1. Of the Heavens belonging to Mercury *and* Venus.

2. He imagined alſo, that the Heavens of *Mercury* and *Venus*, beſides that Motion which is common to all the Heavens from Eaſt to Weſt, had a particular Motion of their own, by which they were carried from Weſt to Eaſt with their Epicycles, in the Circumference of which theſe Stars were placed, the upper Part whereof moved from Weſt to Eaſt, and the lower Part from Eaſt to Weſt.

2. Of the Epicycles of Mercury *and* Venus.

3. Further, he imagined, that the Epicycles of *Mercury* and *Venus*, were carried about by their proper Heavens in one Year's Time, and had their Centers continually almoſt under the ſame Point of the Zodiack as the Sun.

3. Of the Courſe of theſe Epicycles.

4. Laſtly, he ſuppoſed the Epicycle of *Mercury* to be about fifty-ſix *Degrees* in its apparent Diameter, and that it revolved about its Center in ſix Months; That the Epicycle of *Venus* was ninety-ſix *Degrees* in Diameter, and that it revolved about its Center in nineteen Months.

4. The Bigneſs of the apparent Diameters of the Epicycles of Mercury *and* Venus.

5. It is not worth while to be particular in ſhewing how all the forementioned *Phænomena* may be ſolved upon theſe *Hypotheſes*, the Thing is too evident to inſiſt upon: It is ſufficient to obſerve only that the Centers of their Epicycles being always very nearly under the Sun, this is the Reaſon why *Mercury* and *Venus* never go beyond a certain Diſtance from it, and becauſe the Time in which theſe Epicycles revolve about their Center, is not commenſurable with the Time of the

5. Why Mercury *and* Venus *go but a certain Diſtance only from the Sun.*

Sun's Revolution in the Ecliptick; therefore the Duration of the apparent Revolutions of *Mercury* and *Venus* in the Zodiack is very unequal.

6. The Obſervations of modern Aſtronomers about Venus.

6. Later Aſtronomers have obſerved, that when *Venus* begins to move from the Sun to the Eaſt, and is but at a little Diſtance from it, ſhe appears very large; whereas when ſhe is at the ſame Diſtance, in moving towards the Sun, ſhe appears very ſmall: On the contrary, when ſhe begins to move from the Sun to the Weſt, ſhe appears very ſmall, but when ſhe approaches the Sun again, ſhe appears very large.

7. Of the various Phaſes of Venus, *and that ſhe turns round the Sun.*

7. This is that *Phænomenon* which I mentioned before, and which was thought inconſiſtent with the Hypotheſis of *Copernicus*, concerning the Motions of *Venus* and *Mercury*: But that Difficulty is intirely removed ſince the Invention of Teleſcopes. For *Galilæus*, who was the firſt that made them long enough to look at the Stars with, obſerved himſelf, and cauſed others to obſerve, that *Venus* was *quite round*, when ſhe appeared large, and that ſhe was *horned* when ſhe appeared ſmall; whence there is no doubt, but that ſhe moves round the Sun, and borrows her Light from him. Hence alſo we learn, that *Venus* is ſometimes further diſtant from the Earth than the Sun is, and then becauſe that Part of her which is illuminated, is turned directly towards us, ſhe appears quite round, and very large: And, on the contrary, at other Times, ſhe is nearer us than the Sun, and then a Part only of the illuminated Half, can be ſeen by us, which makes her appeared *horned*, and very ſmall.

8. That Mercury *turns about the Sun alſo.*

8. Theſe Phaſes of *Venus*, have alſo been taken notice of ſince *Galilæus*'s Time: But as to *Mercury*, our Teleſcopes not being long enough, any more than thoſe of *Galilæus*, we have not yet obſerved what Figure he appears of; but ſince very curious and credible Perſons have aſſured us, that they have ſeen *Mercury* undergo the ſame Changes of its Figure as *Venus*; we ſhall make no Difficulty to ſay, that He turns about the Sun alſo.

9. That Ptolemy's *Hypotheſis about* Mercury *and* Venus *is falſe.*

9. If *Venus* and *Mercury* moved in Heavens lower than the Sun, as *Ptolemy* affirmed; they could never appear quite round, becauſe they could never be far enough diſtant from the Sun: Whence it follows, that his *Hypotheſis*, with reſpect to *Mercury* and *Venus*, is abſolutely falſe.

CHAP.

CHAP. XV.

Of the Phænomena of Mars, Jupiter, *and* Saturn.

1. How to know Mars, Jupiter *and* Saturn.

MARS, *Jupiter*, and *Saturn*, may be diſtinguiſhed from the other Planets, becauſe they appear bigger than *Mercury*, but leſs than the Sun, Moon, and *Venus*: *Jupiter* appears bigger and brighter than *Mars* and *Saturn*: *Mars* is of a reddiſh Colour, and *Saturn* of a Pale one.

2. Of the apparent Motion of theſe three Planets.

2. By comparing theſe three Planets with the fixed Stars, we obſerve, that they move from Weſt to Eaſt in Circles which cut the Ecliptick in Points directly oppoſite to each other, and which make different Angles with it; *Mars*'s Circle declines from the Ecliptick, one *Degree* and fifty *Minutes*; and *Saturn*'s, two *Degrees* and thirty one Minutes.

3. The Time of their Revolutions.

3. *Mars* performs a Revolution in his Circle, in a Year and three hundred and thirty-two Days; *Jupiter*, in about eleven Years and three hundred and eighteen Days; and *Saturn*, in about twenty-nine Years, and a hundred and eighty three Days.

4. How theſe Planets appear ſometimes Direct, ſometimes Stationary, and ſometimes Retrograde.

4. The apparent Motion of theſe Planets, is not at all regular; for ſometimes they ſeem to move from Weſt to Eaſt, and then they are ſaid to be *Direct*, ſometimes they appear for ſeveral Days together in the ſame Place of the Firmament, then they are ſaid to be *Stationary*; and at other Times they ſeem to go back to the Weſt again, and then they are ſaid to be *Retrograde*; after this they become again *Stationary*, and then *Direct*.

5. Of the Times of their Retrogradation.

5. From the Time that *Mars* is in the Middle of his Retrogradation, to the next Time of his being in the ſame State, is about two Years and forty-nine Days: *Jupiter*, from the middle Time of his Retrogradation, to the middle of the next, is about one Year, and thirty-three Days; and *Saturn* about one Year and thirteen Days.

6. That they are always retrograde, when the Earth is betwixt them and the Sun.

6. Whatever Inequality there be in theſe Planets in the Times from one Retrogradation to the next, yet in this they all agree; that every one of them is always *retrograde*, when [illegible] he Sun and it.

7. The

7. Mars hath more Retrogradation than Jupiter, *and* Jupiter *more than* Saturn.

7. The Arch in the Zodiack which *Mars* paſſes thro' when he is *retrograde*, is bigger than that which *Jupiter* paſſes through when he is *retrograde*; and the Arch which *Jupiter* paſſes through when he is *retrograde*, is bigger than that which *Saturn* paſſes through when he is *retrograde*.

8. That theſe Stars appear bigger when they are retrograde, than when they are direct.

8. The apparent Bigneſs of theſe three Planets increaſes, when they become *retrograde*. *Mars* appears then ſix times as big as when he is *direct*; *Jupiter* about three times as big; and *Saturn* almoſt as big again.

9. None of the other Planets are ever hid by the Interpoſition of theſe.

9. None of theſe three Planets were ever ſeen to paſs betwixt the Sun and the Earth; but they are often ſeen to paſs betwixt the Earth and the fixed Stars.

CHAP. XVI.

Conjectures whereby to explain the Phænomena of Mars, Jupiter, *and* Saturn.

1. Of the Heavens belonging to Mars, Jupiter *and* Saturn.

PTOLEMY aſcribed to each of theſe Planets its proper Heaven, immediately beyond the Sun's Heaven, but a great deal nearer than the Firmament; he ſuppoſed *that* of *Mars* to be neareſt us, *that* of *Jupiter* to be next, and *that* of *Saturn* to be the fartheſt.

2. Of their Epicycles.

2. He affirmed, that every one of theſe Heavens had an Epicycle belonging to it, in the Circumference of which the Planet was fixed; that the Epicycle of *Mars* appeared larger than that of *Jupiter*, and the Epicycle of *Jupiter* larger than that of *Saturn*.

3. Of the Motion of the Heavens belonging to Mars, Jupiter *and* Saturn.

3. Beſides the diurnal Motion of theſe Heavens from Eaſt to Weſt, they have a proper Motion of their own from Weſt to Eaſt; by which their Epicycles are carried along through all Parts of the Zodiack, thro' which we ſaid theſe Planets did paſs, and their Revolutions are completed in the Times (before-mentioned when we were ſpeaking of their *Phænomena*) which theſe Planets take up in deſcribing an entire Circle under the fixed Stars.

6 Whilſt

4. Whilst these Epicycles are carried along in this manner by those Heavens which contain them, they also turn about their own Centers, and carry every one its Planet along with it, from West to East in its upper Part, and from East to West in its lower Part; and the Times of the entire Revolutions of these several Epicycles, are those before-mentioned, between the middle of each *Retrogradation*, and the Middle of the following one.

4. Of the Motion of their Epicycles.

5. It is evident, that these *Hypotheses* will not only explain the apparent Motion which we observe in these Planets, by which they seem to turn about the Earth in Twenty-four Hours; but also their Motion from West to East beneath the fixed Stars; under which each Planet ought to appear, First, To advance very sensibly towards the East, or to be *direct*, when it is in the upper Part of its Epicycle; because its Motion is then compounded of *that* with which it moves in its Epicycle, and of *that* with which the Epicycle it self moves in its Heaven also. Secondly, Each Planet ought to appear *retrograde*, when it is in the lower Part of its Epicycle; because the Motion about the Center of it, carries it further towards the West, than the Motion of the Heaven in which the Epicycle is carried, does towards the East. Lastly, Each Planet ought to appear *Stationary* when it is in either Extreme of the lower Half of the Epicycle, because then, in turning about its Epicycle, it advances neither more nor less towards the West, than it is carried towards the East by the Motion of its Heaven.

5. That these Motions will explain the Directions, Stations, and Retrogradations of Mars, Jupiter *and* Saturn.

6. The Retrogradation of *Mars* ought to take up a larger Arch of the Zodiack than that of *Jupiter*, because *Mars*'s Epicycle is supposed to be larger than *Jupiter*'s; and for the like Reason, *Jupiter*'s Retrogradation ought to take up a larger Part of a Circle than *Saturn*'s.

6. Why Mars *appears to have more Retrogradation than* Jupiter, *and* Jupiter *more than* Saturn.

7. When a Planet is retrograde, it ought to appear bigger than when it is direct, because it is then nearer to us, being in the lower Part of its Epicycle.

7. Why these Planets appear bigger when they are retrograde.

8. The apparent Bigness of *Mars* ought to increase more sensibly than that of *Jupiter* or that of *Saturn*, because *Mars* being nearer to us, his Approach towards the Earth, (which is the whole Length of the Diameter of his Epicycle,) is considerably more in proportion to his Distance, than the Approach of either of the other: For the same Reason, the apparent Bigness of *Jupiter* ought more sensibly to alter than that of *Saturn*.

8. Why the apparent Bigness of Mars *increases more than that of* Jupiter.

9. The

9. Why the fixed Stars are often hid by the Interposition of these three Planets, but never any other of the Planets.

9. The Heavens belonging to these three Planets being placed beyond the Heaven belonging to the Sun; it is impossible that they should ever pass betwixt the Sun and the Earth; but they may very often hide some of the fixed Stars, because they are supposed to be below the Firmament.

10. Of the Satellites *of* Jupiter.

10. *Galilæus*, by making use of Telescopes, first observed those four small Stars, which I mentioned before, which always accompany *Jupiter*, about whom they move both Ways, sometimes to the East, and sometimes to the West, at unequal Distances. These he named the *Medicæan Stars*, but they are now called the *Satellites* or *Guards* of *Jupiter*.

11. Of the various Figures of Saturn.

11. *Galilæus* also observed, that *Saturn* was found to alter his Figure, He sometimes appearing round, and at other Times oval; but we having made use of longer Telescopes than his, have observed *Saturn* to appear successively under those Figures which are * here represented.

*Tab. XII. Fig. 2.

12. Of a small Star perpetually attending Saturn.

12. We also observe [1] a small Star, which seems to describe an oval Figure about *Saturn*, the longer Diameter of which is on that Side where *Saturn* appears longest.

13. Of the Motion of Jupiter's *Satellites.*

13. As to the small Stars which accompany *Jupiter*, *Galilæus* was of Opinion, that they turned about this Planet, and described Circles which are all in the same Plane; which Plane continued, would pass through the Center of the Earth. Mr. *Cassini*, Professor at *Boulogne*, found by very exact Observations, that the first of these four Stars was distant from *Jupiter* on either Side, five Semi-diameters of this Planet, and his Periodical Revolution one Day, eighteen Hours, and Twenty-eight Minutes: That the Second, which is a little bigger, was distant on either Side, eight Semi-diameters, and his Periodical Revolution, three Days, thirteen Hours, and eighteen Minutes: That the Third, which is the biggest of them all, was distant on either Side, thirteen Semi-dia-

1 *A small Star*, &c.) Nay there are Five, as was said before, which *Cassini* and *Hugenius* have observed to revolve about *Saturn*; the Periodical Terms of which are these. The first or innermost, 1 Day, 21 Hours, 18′, 31″; The second, 2 Days, 17 Hours, 41′, 27″; The Third, 4 Days, 13 Hours, 47′, 16″, The Fourth, 15 Days, 22 Hours, 41′, 11″; The Fifth, 79 Days, 7 Hours, 53′, 57″. The Distance from the Center of *Saturn* in Diameters of the Ring, Of the First, is almost 1; of the Second $1\frac{1}{4}$; of the third, $1\frac{3}{4}$; Of the Fourth 4; Of the Fifth, 12. See *Hugenius's Planetary Worlds in English, Edit. Sect. pag.* 116.

meters,

meters, and his Periodical Revolution, seven Days, three Hours, and Fifty-seven Minutes. Lastly, That the Fourth, which is the least of all, was distant on each Side, Twenty-three Semi-diameters, and his Periodical Revolution sixteen Days, eighteen Hours, and nine Minutes.

14. That Jupiter *turns about his own Center.*

14. We cannot conceive how these four small Stars can move in this manner about *Jupiter*, and continue their Motion, unless they be[1] carried by a small Vortex of Matter which surrounds *Jupiter*. But because it would from hence follow, that *Jupiter* also ought to turn about his own Center, we should perhaps have had some Doubt about this, notwithstanding it seems so agreeable to Reason, if we had not been lately convinced of the Truth of it, by an excellent Observation made by *Cassini*. He was the first that took notice of it, and was the Occasion of others taking notice afterwards of a certain Spot upon the Body of *Jupiter*, which beginning to appear on one Side of this Planet, afterwards appeared towards the Center, and then on the other Side: After this it withdrew for some Time quite out of Sight, and then began to appear again on the same Side where it was first seen; The Time which this Spot, and consequently *Jupiter* it self, takes up in compleating one Revolution, is about the Space of nine Hours.

15. That Mars *also turns about its own Center.*

15. There hath been the like Spot seen also upon the Body of *Mars*, which proves, that this Planet also turns about its Center, in about the Space of Twenty-four Hours.

16. A Conjecture how to explain the different Appearances of Saturn.

16. *Galilæus* was surprized at the alterations of the Figure of *Saturn* without being able to find out the Cause; and so have a great many Philosophers been, who have in vain perplexed themselves about it. But not long since, Mr. *Hugens*, a *Dutch* Gentleman, has very luckily thought of an Explication of this Phænomenon, by supposing that *Saturn* is a spherical Body surrounded at a certain Distance, by a Ring which is very thin[2] but of a considerable Breadth, the Plane of which Passes through the Center of *Saturn*; and he supposes

1 *Carried by a small Vortex*, &c.) See *the Notes on Chap.* XXV. *Art.* 22. *of this Part.*

2 *But of a considerable Breadth*, &c.) To which we may add; that the Plane of the Ring is so inclined to the Ecliptick, that about the Signs of *Aries* and *Libra*, the Ring can scarce be seen at all; but about the Signs of *Cancer* and *Capricorn*, it appears like two broad Handles.

this

this Ring, as well as *Saturn* it ſelf, to be illuminated by the Sun.

17. An Explication of the Figures of it. Tab. XII. Fig. 2.

17. This being ſuppoſed, he ſhews that *Saturn* ought to appear round, as it is repreſented in A, when his Situation is ſuch, that if the Plane of his Ring be continued, it would paſs through the Earth; becauſe the Thickneſs of this Ring is only turned towards us then, which Thickneſs cannot be perceived; but when the Ring is in any other Situation, ſo that the Plane of it is viſible to us, then it ought to appear to us of an Oval Figure, ſuch as B, C, or D, which muſt be ſo much the bigger, as our Eye is elevated above the Plane of it.

18. Of the Motion of the Star which attends Saturn.

18. As to the little Star which accompanies *Saturn*, he ſuppoſes *that* to move in the Plane of this Ring, and that it compleats its Revolution about this Planet, in the Space of ſixteen Days or thereabouts.

Tab. XII. Fig. 3.

19. All the ſeveral Parts of the World, which we have hitherto treated of, put together, and diſpoſed in the Order in which we have mentioned them, will compoſe the following Figure, which repreſents the whole World, according to the Hypotheſis of *Ptolemy*.

The Second Part of Coſmography.

O R,

An Explication of the Phænomena, upon Suppoſition that the Earth turns about its own Center in twenty-four Hours.

CHAP. XVII.

A Caution about the Poles and the Circles.

1. Of the Poles of the Earth.

UPON Suppoſition, that the Earth turns about its own Axis in twenty-four Hours, (by which the apparent Motion of the Heavens is explained,) the two Points of its Superficies which turn about their own ſelves only, are the *true Poles*; and the Circles which every other Point

Point of its Superficies defcribes, are the *Circles of Longitude upon the Earth*, the largeft of which Circles is the *Terreftrial Equator* or the *Equinoctial Line*.

2. So likewife the two Points in the Heavens, which are directly againft the two Poles of the Earth, and which feem never to move, whilft all the reft feem to turn about, thefe are *the apparent Poles of the Heavens*; and the Circle, which we imagine to be directly againft the Earth's Equator, is *the apparent Equator of the Heavens*.

2. Of the apparent Pole in the Heavens.

3. When we would defcribe the *Horizon* of any particular Place upon the Earth's Superficies, we imagine, alike in both Hypothefes, that this *Horizon* is ninety Degrees diftant every Way from the Place, and the *Horizon* which we imagine in the Heavens neceffarily paffes through all thofe Points, which are directly againft the Earth's *Horizon*; now upon Suppofition that the Earth moves, thefe Places in the Heavens are the fame as if the Motion were really in the Heavens; therefore it follows, that upon either Hypothefis, the *Horizon* is always the fame.

3. Of the Horizon.

4. *The Circles of Latitude*, and the *Meridians upon the Earth* are always the fame: For fince the *Meridians* in the Heavens, are always fuppofed to be in thofe Places which are directly againft the Earth's *Meridians*, and that thefe Places are always the fame upon either Hypothefis; it follows, that the *Meridians* in the Heavens, ought to be the fame here, as thofe before defcribed, when we allowed the Hypothefis of the diurnal Motion of the Heavens.

4. Of the Meridians upon the Equator.

CHAP. XVIII.

An Explication of the Sun's Phænomena.

FIRST. Though we conceive the Diftance from hence to the Sun to be very great; yet the Diftance from hence to the Firmament [1] is ftill vaftly greater. We may indeed conceive it as great as we pleafe, be-

1. The firft Suppofition.

[1] *Is ftill vaftly greater,* &c.) See *the Notes on Chap.* XXV. *Art.* 3. *of this Part.*

caufe there has not yet been any Method found out of determining it.

2. The fecond Suppofition.

2. Secondly. We muft fuppofe, that [1] the celeftial Matter which furrounds the Sun, and which diffufes it felf all Ways to a Diftance much lefs than that where the fixed ftars are, but much greater than that where we are; turns from Weft to Eaft about the Sun and carries the Earth along with it in fuch a manner, as without hindring its Revolution about its own Center in Twenty-four Hours, to move very nearly parallel to it felf, and to defcribe about the Sun every Year, a Circle fomewhat excentric; to the Plane of which its Axis is inclined Twenty-three Degrees and a half.

3. Why the Heavens feem to turn from Eaft to Weft.

3. Upon this Hypothefis, it is evident, Firft, That the Sun as well as the whole vifible Heavens, ought to feem to defcribe every Day, from Eaft to Weft, a Circle parallel to the Equator.

4. Why the Sun appears to move from Weft to Eaft in the Ecliptick.

4. Secondly. Becaufe the Earth goes about the Sun from Weft to Eaft, the Sun muft neceffarily feem to move from Weft to Eaft in the Firmament, in which it would appear to defcribe a Circle, which would indeed be the fame as the Equator, if the Axis of the Earth were perpendicular to the Plane of its annual Circle, but muft now differ from it, and interfect it at an Angle of Twenty-three Degrees and a Half, which is its Diftance from it, by reafon the Axis of the Earth has thus much Inclination to its Plane.

5. That all the other Phænomena of the Sun depend upon what we have now mention'd.

5. Having fhewn how the Sun ought to appear, to turn about the Earth from Eaft to Weft every Day, and to defcribe Circles parallel to the Equator; and further, that it ought alfo to have an apparent Motion from Weft to Eaft in the Ecliptick, which it feems to move thro' in a Year, it is eafy to fee that this will folve all the particular Phenomena before-mentioned; I fhall not therefore fpend any further Time in explaining them.

6. That the apparent Magnitude of the fixed Stars, and the Pole of the Heavens ought never to alter.

6. However I cannot omit in this Place, two very important Things, belonging to the Subject we are now treating of. The Firft is, That though the Diftance betwixt the Earth and fome of the fixed Stars, increafes or diminifhes in fix Months time, by the Length of the whole Diameter of the Earth's annual Circle; yet thefe Stars ought not to appear bigger at one Time than at another. The Second is, that though the Circle which the Earth defcribes about the Sun, is very large confidered by itfelf, and with regard to thefe Meafures which

1 *The Celeftial Matter* &c.) See *the Notes on Chap.* XXV. *Art.* 22. *of this Part.*

we here make use of upon the Earth, yet notwithstanding, the apparent Pole in the Heavens ought not to change its Place, but always throughout the whole Year, to keep the same Distance from the Pole Star.

7. As to the first of these two; besides the Proof of it from hence, that the Diameter of the Earth's annual Circle, as large as it seems to us to be, is not at all sensible, but a mere nothing, compared with [1] the immense Distance that there is betwixt the Earth and the fixed Stars; besides this, I say, there is another Reason which I think no one has hitherto taken Notice of, and that is this; We judge of the Magnitude of a fixed Star by the Bigness of that Part of the Bottom of the Eye which is shaken, when we look upon it: But the Impression which a Star makes, is so strong, that it spreads over a Space a thousand Times bigger in Diameter perhaps than the true Image; so that we see it [2] far bigger than it ought to be seen. This being supposed; if we imagine that the Diameter of the Earth's annual Circle were so large, compared with the Distance betwixt the Starry Heaven, that we were twice as near a fixed Star, one Time of the Year, than we are at another, its true Image out to be twice as large; but the trembling or shaking, if it extends itself to its usual Distance all round, must cause the Diameter of the false Image, by which we judge of the Distance of a Star when we are nearest it, to be greater than the Diameter of the false Image when we are furthest off it, by a thousandth Part only of its Diameter, which is not at all sensible: It follows therefore, that the apparent Magnitude of the Image ought not sensibly to increase.

7. Why the apparent Magnitude of the fixed Stars never alters.

8. As to *the apparent Pole in the Heavens* never altering its Place, that is entirely owing to the immense Distance of the fixed Stars from us, and to the Earth's Axis always keeping parallel to itself. For hence it follows, that the Alteration of the Pole in the Heavens, being exactly equal to the Change of the Place of the Earth's Pole; the Alteration of the Pole in the Heavens cannot be at all sensible, because of its great Distance.

8. Why the Distance of the apparent Pole in the Heavens from the Pole-Star never alters all the Year.

1 *With the immense Distance.*] See Notes on Chap. xxv. Art. 3. of this Part.

2 *Far bigger than it ought.*] See Notes to Chap. xxxi. Art. 26. of the first Part.

CHAP. XIX.

An Explication of the apparent Motion of the fixed STARS.

1. That the apparent diurnal Motion of the fixed Stars follows from the Earth's turning about its own Center.

I Am not now ſpeaking of the diurnal Motion of the fixed Stars: If the Earth turns about its own Center, they muſt neceſſarily ſeem ſo to move: The Queſtion now is concerning another Sort of Motion, by which every fixed Star ſeems to increaſe its Longitude ſince *Hipparchus*'s Time.

2. A Conjecture for explaining the periodic Revolution of the fixed Stars.

2. In order to account for this Phænomenon, we need only to ſuppoſe, that the Earth, in its annual Revolution about the Sun, does not keep an exact Paralleliſm, but that it librates a very little, ſo that in a great many Thouſand Years, each of its Poles deſcribe a ſmall Circle from Eaſt to Weſt.

3. Why the fixed Stars ſeem to move from Weſt to Eaſt.

3. Upon this Suppoſition, the *Earth's Equinoctial Circle* will be applied to different Parts of the Heavens, and therefore the *Equinoctial Circle of the Heavens* muſt alter in the ſame manner, and cut the Ecliptick in different Points, ſucceeding each other from Eaſt to Weſt. Now ſince we reckon the Longitude of the Stars from the Point of Interſection of theſe two Circles, it muſt neceſſarily increaſe a little every Century.

4. Why the Motion of the fixed Stars from Weſt to Eaſt is unequal.

4. The Alteration of Longitude that happens to any one fixed Star in a certain Number of Years, muſt be the ſame in every other fixed Star; but all the fixed Stars together may alter their Longitude more ſenſibly in one Age than in another, if the Libration of the Earth be greater in one Age than in another.

5. Why the Declination of the Ecliptick leſſens from Time to Time.

5. In order to explain how the Declination of the Ecliptick is leſſened, as Aſtronomers have from Time to Time obſerved, ſince the Days of *Hipparchus*; we need only ſuppoſe this, that the Libration of the Earth, hath cauſed its Axis to be a little more elevated above the Plane of the Ecliptick: And from hence it will follow, that the Equinoctial Circle in the Heavens muſt approach ſomewhat nearer to the Ecliptick in which the Sun ſeems to move: There being therefore not ſo much Diſtance betwixt the Ecliptick and the Equator, as there was before, we imagine the former of theſe Circles to have come nearer to the latter.

6. The Libration which we here aſcribe to the Earth, makes the Poles of it alter their Places; whence it follows, that they ought not always to correſpond to the ſame Places in the Heavens; and thus late Aſtronomers have obſerved, that the Polar Star is much nearer the Pole now, than it was in the Days of *Hipparchus*.

6. That the Poles of the Earth, do not anſwer to the ſame Places in the Heavens that they formerly did.

7. But no Libration or other Notion whatſoever, which we ſuppoſe in the Earth, [1] can cauſe any Alteration in *the Elevation of the apparent Pole of the Heavens* above the *Horizon* in any particular Place, ſo long as the ſame Points of the Superficies of the Earth, continue to be the Poles of it. Becauſe, as the Poles alter their Places, the whole Earth is altered likewiſe, and conſequently the *Horizon* in proportion. Thus if we ſuppoſe the Pole of the Earth to correſpond to a Place in the Heavens, differing ſix Degrees from the Place to which it correſponds now; the *Horizon* which we conceive upon the Earth, would correſpond to a different Place alſo, from what it did before, by the ſame Number of Degrees: Whence it follows, that the Elevation of the Pole above the *Horizon* muſt be always the ſame.

7. That the Libration of the Earth, does not alter the Elevation of the Pole.

8. It is true, that if we ſuppoſed the Earth to turn upon different Poles from what it does now, then this Elevation would indeed be altered: And this would agree with the Opinion of ſome Moderns, who pretend, that the Latitude of *Paris*, and conſequently the Elevation of the Pole, is not the ſame that it was formerly, and that the Limits of the Sun's Setting are alſo altered.

8. How the Elevation of the Pole above the Horizon may be altered.

1 *Can cauſe any Alteration,* &c) The Elevation of the Pole it ſelf, would not indeed be altered, but its Diſtance from that *Star* which is now called the *Pole-Star*, would be very much altered.

CHAP. XX.

An Explication of the Motions of Mercury *and* Venus.

1 There is no need of making any new Supposition, in order to explain the Phænomena of Mercury *and* Venus.

WE have been already assured, that *Mercury* and *Venus* are much nearer the Sun than the Earth is; which being granted, there is no need of supposing any Thing new, in order to explain the Phænomena; they all necessarily follow, from what has been already supposed in order to explain the Phænomena of the Sun.

2. How Mercury *and* Venus *seem to turn round from East to West every Day.*

2. For, First, since the Earth turns about its own Center from West to East in twenty-four Hours; *Mercury* and *Venus* must necessarily appear to move from East to West, and to describe every Day a Circle parallel to the Equator.

3. How they ought to appear to move from West to East.

3. They ought also each of them to describe a Circle about the Sun from West to East, because they are contained [1] in the cælestial Matter, which carries the Earth about in that manner.

4. That they ought to describe a great Circle.

4. Further, according to this Law of *Mechanicks* founded in Reason and Experience, *viz. that every Body which moves in a Circle, endeavours to describe the largest Circle that it can*; *Mercury* and *Venus*, as well as the Earth, ought always to be in the Zodiack; because that is the largest Circle which the cælestial Matter in which they are carried describes.

5. That they ought to finish their Courses in less than a Year.

5. The Circles which *Mercury* and *Venus* describe about the Sun, being less than that in which the Earth is moved about it; we ought to conclude, that the true periodical Revolutions of these two Planets, are finished in less than a Year.

6. That they ought to appear to take up more Time in a Revolution than they really do take up.

6. However, they ought to appear to take up more Time in making a Revolution, than they really do take up; because we call *that* the Beginning of their Periods, when these Planets are between the Sun and the Earth; and we suppose this Period not finished till we find them there again: But because the Earth changes its Place also, whilst the Planets make their Revolutions, that also

1 *In the cælestial Matter*, &c.) See the Notes upon Chap. XXV. Art. 22. of this Part.

will be in a different Place from what it was in at the Beginning: Whence it follows, that the apparent Period of every one of the Planets, muſt neceſſarily comprehend not only a whole Circle, but as much more alſo, as the Earth has paſſed through in the ſame Time.

7. This being well underſtood, it will not appear at all ſtrange, that *Venus*, which moves in a leſs Circle than the Earth, ſhould notwithſtanding appear to take up nineteen Months: For the Earth having in this Time gone above a Revolution and a half; *Venus* muſt have made more than two Revolutions and a half, when we think, that ſhe hath made but one; whence it follows, that ſhe finiſhes her Courſe in leſs than eight Months.

7. That Venus *finiſheth her Courſe in leſs than eight Months.*

8. And becauſe *Mercury* ſeems to make his Revolution in ſix Months or thereabouts, during which Time, the Earth make[illegible] a Revolution; therefore *Mercury* really finiſhes his Co[illegible] in about four Months.

8. That Mercury *finiſhes his courſe in about four Months.*

CHAP. XXI.

An Explication of the Motion of Mars, Jupiter, *and* Saturn.

SINCE we are already aſſured, that *Mars*, *Jupiter*, and *Saturn*, do indeed ſo move about the Sun, that the Circles which they deſcribe, contain the Earth's Circle within them; this is ſufficient to convince us, that theſe Planets alſo [1] ſwim in the cæleſtial Matter, and that they are further diſtant from the Sun than the Earth is.

1 That Mars, Jupiter *and* Saturn, *are further diſtant from the Sun than the Earth is.*

2. This being ſuppoſed, it follows, that *Mars*, *Jupiter*, and *Saturn*, muſt not only ſeem to turn about the Earth from Eaſt to Weſt in twenty-four Hours; but muſt alſo be carried along by the cæleſtial Matter which contains them, in the ſame manner as *Mercury*, *Venus*, and the Earth are carried.

2. How they appear to turn about the Earth in Twenty-four Hours from Eaſt to Weſt.

[1] *Swim in the cæleſtial Matter*, &c. See *the Notes on Chap.* XXV. *Art* 22.

3. Why Mars, Jupiter, and Saturn, take up so many Years in turning about the Sun.

3 According to the Mechanick Law before mentioned, the Circles which *Mars*, *Jupiter*, and *Saturn* describe, ought to be under the Zodiack; and as they are larger than that which the Earth describes, it is easy to see, that they cannot finish their Course in so short a Time as the Earth does hers. Thus we see the Reason why *Mars* finishes his Course in near two Years, *Jupiter* in Twelve, and *Saturn* in Thirty, as they are observed to do, *viz.* because they being further distant from the Sun than the Earth is; the cœlestial Matter at such Distances, ought to take up proportionable Times to revolve round.

4. How these Planets appear retrograde.

4. Though these Planets move always directly on, and never stand still, or go backwards, yet they must necessarily appear to be stationary and retrograde, and that at the Time when we think they should be so, *viz.* they seem retrograde as often as the Earth passes betwixt the Sun and them; because we then move the same Way as they do, but quicker than they; therefore we must see them applied to different Parts of the Starry Heaven every Day, and move the contrary Way to that which we go.

5. How they appear Stationary.

5. And as to their Stations, we ought to see them before and after every Retrogradation, because then the Determination of the Earth's Motion, is somewhat oblique to the Determination of the Planet's Motion: So that the Velocity with which we are moved, is sufficient only to make us see the same Planet in the same Place for several Days together.

6. A more particular Explication of their Stations and Retrogradations. Tab. XIII. Fig. 2.

6. This will be clearer by looking on the Figure. Let us suppose, for Instance, the Circle here marked A to be the Sun; B C to be the Earth's annual Circle; D M the Orbit of one of the Planets, *Mars*, *Jupiter*, or *Saturn*; and that F G represents the Starry Heaven: This being so, if we conceive the Planet to be at D, and the Earth at B, (so that we are about to pass betwixt it and the Sun) we must then see it under the Place of the Heaven marked F. Further, if when the Earth is got to H, the Planet, which moves slower, is got to E only, we ought to see it in F still, the same Place of the Heaven; and this explains the Station which precedes the Retrogradation; after this, if we suppose the Earth to be got as far as I, and the Planet to L, then we ought to see it under the Place of the Heaven marked G, which is more West than the Point F, where it appeared before; which explains the Retrogradation;

Lastly,

Laftly, if we fuppofe the Earth to be got to C, and the Planet to M, we ought ftill to fee it in the fame Place G; and this explains the Second Station, which follows the Retrogradation.

7. Whence it is that Mars, Jupiter, *and* Saturn, *are unequally retrograde.*

7. The Nearnefs of *Mars*, makes the Arch FG, that is, the *Parallax*, and his Retrogradation, larger than the *Parallax* and Retrogradation of *Jupiter*. And becaufe *Jupiter* is nearer us than *Saturn*, for the fame Reafon his *Parallax* and Retrogradation are larger than thofe of *Saturn*: Whence it follows, that when *Mars* is retrograde, he ought to appear to move through a bigger Arch of the Heavens than *Jupiter*, and *Jupiter* through a bigger than *Saturn*.

8. Why thefe Planets appear bigger when they are retrograde, and why their apparent Bignefs increafes unequally.

8. According to this *Hypothefis*; when the Earth is betwixt the Sun and one of thefe Planets, we are nearer it by the whole Length of the Diameter of the Earth's annual Orbit, than when the Sun is between this Planet and us, and therefore the Planet ought to appear bigger; now this happens at the Time of its Retrogradation; it is evident therefore, that the apparent Bignefs of a Planet when it is retrograde, ought to exceed its apparent Bignefs when it is direct. And becaufe the Length of this Diameter by which we are nearer to *Mars*, bears a greater Proportion to that Diftance which we were from him before; than the fame Diameter, by whofe Length we are nearer *Jupiter* alfo, does to the Diftance we were from *Jupiter*; it follows, that the Increafe of the apparent Bignefs of *Mars*, ought to be greater than the Increafe of the apparent Bignefs of *Jupiter*: And becaufe our Approach to *Saturn* is fcarce perceivable, becaufe of his great Diftance; therefore his apparent Bignefs is hardly at all increafed, when he becomes retrograde.

CHAP. XXII.

An Explication of the Moon's Motion.

1. That the Moon is contained in the Earth's Vortex.

THE Eclipses of the Moon and of the Sun; the apparent Bigness of the Moon, the Strength of its Light, and its Parallax, do all shew, that the Moon is not very far distant from us: Wherefore it is natural to think, that it is contained in [1] that small Vortex, in the Middle of which the Earth is placed.

2. That the Moon ought to be carried about the Earth from West to East.

2. And because the Matter of this Vortex is turned about its Center from West to East, it must carry the Moon along with it in that Manner about the Earth: But since the Circle described by the Moon, is much larger than the Globe of the Earth; it is reasonable to think, that if the Earth makes a Revolution of twenty-four Hours, the Moon cannot make one in less than a Month.

3. How the Moon may seem to go round in Twenty-four Hours, from East to West, and in a Month from West to East.

3. This Length of Time which the Moon takes up in revolving about the Earth, is the Reason why she appears to make almost an entire Revolution from East to West every Day, whilst the Earth revolves about its Center in the same Time from West to East: But this does not hinder, but that in a Month's Time or thereabouts, the Moon may run through all the Signs of the Zodiack from West to East.

4. Why the Motion of the Moon from West to East, is more sensible at the Conjunctions and Oppositions, than at the Quadratures.

4. We must take notice here, that the Vortex in which the Moon is carried, and in whose Center the Earth is placed, being compressed between the Heavens of *Venus* and *Mars*, is not exactly round, but of an oval Figure; the lesser Diameter of which, if continued, would pass through the Center of those Heavens, that is, through the Sun: This being so, the fluid Matter of this small Vortex, which runs round the Earth, must necessarily move quicker in those Places where the Passage is straighter than in those Places where it is larger: Wherefore the Moon, which is carried in this Matter, being in the straightest Places, at the Times of its Conjunctions and Oppositions, its Motion towards the East, ought to be more sensible at those Times, than at any other.

1. *That small Vortex, &c.*) See *the Notes on Chap.* XXV. *Art.* 22.

5. The

5. The Figure of the Moon's Path, which is that of an Oval, hinders it from being [1] ſo far diſtant from the Earth, at its Conjunctions and Oppoſitions, as at its Quadratures. And hence it is, that about the Time of the Conjunctions and Oppoſitions, the Moon's Diameter ought to appear largeſt.

5. Why the Moon is at its greateſt Elongation in the Quadratures.

6. If the Motion of the Matter of a ſmall Vortex in which the Moon is carried, were to accommodate itſelf to the Earth's Motion only, then the Moon would appear to move from Weſt to Eaſt under the Equator; and on the other Hand, if the Motion of this Matter, accommodated itſelf to the Motion of the great Vortex about the Sun only; then the Moon would appear to move always under the Ecliptick; but being to accommodate itſelf to both theſe Motions, it follows, that the Moon can neither be carried under the Equator, nor under the Ecliptick, but in a third Circle, which approaches nearer the Ecliptick than the Equator, becauſe the Moon is nearer the Sun's Vortex, than ſhe is the Globe of the Earth.

6. Why the Moon does not always move exactly under the Ecliptick.

7. The different Phaſes in which the Moon appears at different Times, and the Eclipſes of the Sun, are explained in the ſame manner in this, as in the foregoing Hypotheſis.

7. That the different Phaſes of the Moon are explain'd the ſame manner in this Hypotheſis as in the foregoing one.

8. Though according to this Hypotheſis, it is eaſy to imagine a Compoſition of the whole Heavens; yet I thought it proper to repreſent them in the following Figure.

Tab. XIII. Fig. 2.

1 *So far diſtant from the Earth, &c.*) It is to be obſerved however, that the Moon has two *Perigæums* and *two Apogæums*, which very much alters this Matter. See *Tacquet's Aſtron. Book* II. *Chap*. ii. *Numb*. 16.

CHAP.

CHAP. XXIII.

Of the System of Tycho-Brahe.

1. The first Particular in which Tycho *and* Copernicus *agree.*

BESIDES the two Syſtems of the World which were publiſhed by *Ptolemy* and *Copernicus*, *Tycho-Brahe* invented a third, which has ſomething in it common to the other Two: For as to the Poſition of the Parts of the Univerſe, *Tycho* agrees with *Copernicus*, except only in this particular, that he makes the Earth the Center of the fixed Stars.

2. The first Particular in which he agrees with Ptolemy.

2. And in order to explain the Motion of the Heavens, and firſt, the apparent Motion of the whole Heavens, which they ſeem to complete in twenty-four Hours, *Tycho* was of the ſame Opinion with *Ptolemy*, *viz.* that the Earth is at reſt in the Center of the World, and that the whole Machine of the Heavens is turned about it from Eaſt to Weſt in the Space of a Day, by the Action of the *Primum Mobile.*

3. The second Particular in which he agrees with Ptolemy.

3. He alſo explains the particular apparent Motion of the fixed Stars in the ſame manner as *Ptolemy* and his Follwers did.

4. The second Particular in which he agrees with Copernicus.

4. But in order to account for the apparent Motion of the Planets, we may affirm, that he entirely agrees with *Copernicus*, that is, he ſuppoſes *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*, to revolve about the Sun, and the Moon about the Earth, in the Times mentioned by *Copernicus.* He only adds further of his own; that the Sun revolves about the Earth from Weſt to Eaſt, and carries along with it, that huge Maſs, of which it is the Center, conſiſting of all the Heavens of the Planets, whole and entire, and always parallel to itſelf; in ſuch a manner, that the Earth, being always at an equal Diſtance from the ſeveral Parts of the Starry Heaven, is to be found ſucceſſively in all the Places contained between the Heavens of *Venus* and *Mars*, to which *Copernicus* ſuppoſes it applied in the Space of a Year.

5. Wherein the Hypothesis of Tycho *differs from that of* Copernicus.

5. So that all the Difference that there is betwixt the Opinion of *Copernicus* and *Tycho* with reſpect to the Earth, compared with the fluid Matter of the World through which it moves, or which moves by the Sides of it, conſiſts in this: That *Copernicus* ſpeaks of the Motion of the Earth, as a Man would do, who was going to explain how he got from *Paris* to *Orleans*, *viz.* by pointing

ing out the Way, and ſaying, that he was carried along in it by the Motion of a Coach and Horſes; whereas *Tycho* in ſpeaking of it, would do like another Man, who, having been in a Coach from *Paris* to *Orleans*, the ſame Way; would not acknowledge, that either the Coach or Horſes moved at all, but affirms, that the Way is moved, and the Wheels of the Coach only turned about their own Axes, and the Horſes only lifted up their Legs, in order to let the Way ſlip under them, and that they might not be carried along with it.

6. They who are well acquainted with the *Hypotheſes* of *Ptolemy* and *Copernicus*, will find no great Difficulty in obſerving how *this* agrees with the *Phænomena*, but will ſee, that it very well explains the Directions, Stations, and Retrogradations of the Planets.

6. That the Hypotheſis of Tycho *explains all the Phænomena very well.*

CHAP. XXIV.

Reflections upon the Hypotheſes of Ptolemy, Copernicus, *and* Tycho.

WE have no Reaſon to think, that the Structure of the World is ſuch, as we have no Idea of; becauſe in Things merely natural, we can always judge of them according to the Ideas and Notions which we have of them. But becauſe we have here propoſed three Notions of the ſame Thing, one of which only can be the true one, we muſt neceſſarily reject two of them as falſe, and retain the other as the only true one.

1. That there can be but one of theſe three Hypotheſes the true one.

2. In order to chooſe which of theſe Opinions we ſhould be of, we muſt throughly conſider the Hypotheſes of *Ptolemy*, *Copernicus*, and *Tycho*, and compare them exactly with each other; for if we find any one of them to contain any Thing contrary to Experience or Reaſon, we ought not to make any Difficulty in rejecting it, in order to our embracing that only, in which there are no ſuch Repugnancies: And if there be no ſuch Repugnancies in any of the three, yet we ought always to fix upon that, which is the moſt ſimple, and has the feweſt Suppoſitions; becauſe the more the Phænomena are, which can be explained by it, without making any new Suppoſitions, the more the Proofs are that it is true.

2. How to make choice of one of theſe Hypotheſes.

3. The

3. The first Reason why we ought to reject the Hypothesis of Ptolemy.

3. The *Hypothesis* of *Ptolemy*, as was before observed, is contrary to Experience, with relation to the different Phases of *Venus* and *Mercury*.

4. The second Reason.

4. It is also contrary to Reason, because it allows of Librations in the Chrystalline Heavens; for this is to admit of a great Alteration, in order to explain a small one: Thus a Body which moves on always the same Way, though with unequal Velocity, does not undergo so much Alteration, as a Body which, having begun to move one Way, moves all at once the opposite Way. To which may be added; that the Libration which is introduced in order to explain the unequal Motion of the fixed Stars, is not sufficient for that Purpose; for Astronomers do very often find that their Calculations do not agree with the Phænomena.

5. The third Reason.

5. It ought also to be rejected, because of the great Number of particular Suppositions, which it contains, and which are made upon all Occasions, in order to explain any new Phænomenon; so that nothing can be deduced from the first Supposition, that will explain any new Thing, and which consequently should be taken for a Confirmation of the *Hypothesis*.

6. The fourth Reason.

6. Further, since he ascribes to the *Primum Mobile*, a Power of carrying along with it from East to West, all the Heavens which are contained in it; we cannot conceive any Reason why it should not carry the Earth along with it also; and that so much the rather, because the Defenders of this *Hypothesis*, suppose it to be an unactive Mass, and are directly against allowing it any particular Motion, by which it might advance as much from West to East, as the *Primum Mobile* would carry it from East to West; which is however the only Thing that they themselves make use of, when they would shew why the Starry Heaven and the Heavens of the Planets, do not finish their Revolutions in the same Time as the *Primum Mobile* does his.

7. That Gravity does not hinder the Earth from being carried about by the Primum Mobile.

7. I know that it is usual to say, that the Gravity of the Earth, hinders it from being moved by the Heavens which incompass it; but I know also that this Reason is not a true one: For, all that Experience teaches us, is; that Gravity is a Quality by which terrestrial Bodies tend to the Center of the Earth, and tend likewise in the same manner to unite with each other: Now it seems as absurd to apply this Gravity to the hindring the Earth's Motion; as it would be to affirm, that a Number of Persons who are in a Boat that turns round,

round, might hinder themſelves from being turned about, by claſping each other, and faſtning themſelves together as cloſe as they could.

8. That according to the Hypotheſis of Ptolemy, *neither Gravity nor Levity, nor the Flux and Reflux of the Sea can be explained.*

8. That the *Hypotheſis* of *Ptolemy* cannot be the true one, is moſt evident from hence; that the Philoſophers of the ſeveral Ages ſince him, have not been able to find out the Reaſon of two Sorts of Motions very conſiderable, and which they themſelves own to be of very great Importance: The firſt of theſe, is that Motion by which heavy Things deſcend downwards, and light Things aſcend upwards, that is, they have not yet been able to ſhew, what Gravity and Levity conſiſt in: The other is that Motion by which the Waters of the Sea riſe and fall twice every Day at certain regular Hours, which is what we call the Flux and Reflux of the Sea.

9. That the Hypotheſis of Tycho *is no leſs defective than that of* Ptolemy.

9. We have as much Reaſon to reject the *Hypotheſis* of *Tycho*, as that of *Ptolemy*; for the Defects are much the ſame in them both: We may indeed affirm, that there are fewer Suppoſitions in it to explain the Motions of the Planets by, and that it accounts very well for the apparent Phaſes of *Venus*; but it muſt be owned, that there is one Thing very ſhocking in it, and which can by no Means be reconciled with Reaſon, *viz.* when it ſuppoſes that Motion, by which the whole Maſs of which the Heavens of the Planets is compoſed, is carried thro' the whole Firmament. For though we ſhould ſuppoſe the Author of Nature, to have impreſſed this Motion upon it at the Beginning; yet we muſt acknowledge, that according to the Laws of Nature, which he himſelf has eſtabliſhed, and by which we ſee all Things are governed, this Motion muſt gradually diminiſh and quite ceaſe at laſt; becauſe, according to the ſame Laws, it muſt be communicated to the cæleſtial Matter, which that Maſs to which *Tycho* aſcribes this Motion, continually turns out of its Place.

10. That the Hypotheſis of Copernicus *is more probable.*

10. The *Hypotheſis* of *Copernicus*, is, without Doubt, the moſt ſimple of the Three: For he makes no more Suppoſitions, than thoſe few which are neceſſary to explain the apparent Motion of the Sun and fixed Stars; and all the Phænomena of the Planets, which he explains afterwards, and eſpecially, the Directions, Stations, and Retrogradations, of *Mars*, *Jupiter*, and *Saturn*, are ſo many Proofs to confirm his *Hypotheſis*, and to induce us to believe that he has hit upon the Truth.

11. A Confirmation of the Hypothesis of Copernicus.

11. It is a ſtill greater Confirmation hereof, if we conſider, that as there is but one Sun to illuminate the Earth and Planets, and that the Planets ſhine by that foreign Light which they borrow from it; it is very probable, that the Earth alſo receives her Light in the ſame manner as the Planets do: For, there is no doubt at all but that they receive theirs by revolving about the Sun, and, as we have good Reaſon to think, by turning about their own Centers likewiſe; (for we are aſſured of this by Obſervation in *Mars*, *Jupiter*, and *Saturn*;) which being ſo, it is highly probable, that the Earth revolves in the ſame manner that *Copernicus* ſuppoſes.

12. That this Hypothesis does not really aſcribe any Motion to the Earth.

12. Now there is this peculiar Advantage in this *Hypotheſis*, that it will ſatisfy not only all reaſonable Perſons, but even thoſe that are very ſcrupulous; by allowing to the former the Liberty of thinking as they pleaſe, and of giving what Name they judge proper to that Tranſlation which the Earth makes; and by ſhewing to the latter, who can by no Means agree, that any Motion at all ſhould be aſcribed to the Earth, that they need not be in the leaſt ſurpriſed at this *Hypotheſis* on that Account, becauſe it is indeed but very improperly, that any Motion is aſcribed to it. For if it be rightly underſtood [1] that the Motion *is nothing elſe but the ſucceſſive Application of the Superficies of any Body, to the different Parts of the Bodies which ſurround it, and immediately touch it*; we ſhall ſee, that what we call the diurnal Motion of the Earth, belongs rather to the whole Maſs compoſed of Earth, Seas and Air, than to the Earth in particular; which ought to be looked upon as at perfect reſt, ſo long as it is carried by the Torrent of Matter in which it ſwims; in the ſame manner as we ſay, that a Man who is aſleep in a Ship, is at reſt, though the Ship really is in Motion. So likewiſe will it appear, that the Motion which we commonly call the annual Motion of the Earth, does not at all belong to it, nor to the Maſs compoſed of Earth, Water and Air, but to the cæleſtial Matter, which carries this whole Maſs about the Sun.

13. That the Objections made againſt the Hypotheſis of Copernicus, *are of no Force.*

13. As to the Objections which are uſually made againſt this *Hypotheſis*, as for Example, that it would from thence follow, that a Stone let fall in the Air from a very high Place, would not fall upon that Place on the Earth which anſwered perpendicularly to it when

1 *That Motion is nothing elſe,* &c.) How weak this is, may be ſeen in the *Notes on Part* I. *Chap.* x. *Art.* 3.

it was let go, but upon another Place to the Weſt of that; becauſe whilſt it is deſcending, the Earth is moved towards the Eaſt, and ſuch like Objections; they cannot be propoſed, but by ſuch as have not been at the Pains to think ſeriouſly upon the different Circumſtances of Motion: For, whoever has in the leaſt conſidered this Matter, will eaſily ſee, that according to the great Law of Nature, *viz. that all Bodies will continue as much as they can, in that State in which they once are*; all the terreſtrial Bodies, which have for ſo long Time turned with the Earth from Weſt to Eaſt, muſt have the ſame Tendency to move that Way, as the Earth itſelf has; conſequently [1] a Stone let fall from a very high Place, cannot deſcend without moving forwards exactly as much as the Earth does; whence it muſt neceſſarily fall upon the Place which correſponded to it perpendicularly when it was let go; and where we ſee by Experience, that it does fall. Nor ought we to think, that the Air, unleſs moved by any external Cauſe, ſuch as the Wind, will at all alter the Line in which the Stone has a Tendency to deſcend in; for the Air itſelf moves towards the Eaſt, in the ſame manner as the Earth does, but it ought to move either quicker or ſlower than the Earth, if it were to accelerate or retard the Stone's Motion.

14. That we think the Hypotheſis of Copernicus, *preferable to the other Two.*

14. After theſe Explanations, [2] we ſhall make no Difficulty of joining with one Party, and declaring for the *Hypotheſis* which is commonly called *Copernicus*'s; ſo that when we mention our *Hypotheſis* hereafter, we are to be underſtood to mean *this*, which in all our Philoſophy we ſhall ſuppoſe to be the true one.

1 *A Stone let fall from a very high Place*, &c.) See *the Notes on Part* I. *Chap.* xiv. *Art.* 3.

2 *We ſhall make no Difficulty*, &c.) You will find a very ingenious Argument, for the Hypotheſis of *Copernicus* above all the reſt, drawn from the Diſtance of the fixed Stars, below in the *Notes upon Chap.* xxv. *Art.* 3.

CHAP,

CHAP. XXV.

Of the Nature of the Stars.

1. That the Sun shines by its own Light.

NO Body doubts, but that the Sun ſhines by its own Light, for we do not ſee any where in the World a more luminous Body for it to borrow its Light from.

2. That the other Planets ſhine by the Light which they receive from the Sun.

2. What was before obſerved, concerning the Moon and *Venus*, ſhews us, that theſe Planets ſhine by the Light which they receive from the Sun; and ſince the other Planets do not appear to have any more Light of their own than *Venus*; and ſince they all revolve about the Sun, as *Venus* and the Earth do, (which looks like ſome Sort of Dependence upon it) it is natural to conclude, that they alſo, like the other, ſhine by that Light only which they receive from the Sun.

3. That the fixed Stars ſhine by their own Light.

3. The fixed Stars ſhine a great deal brighter than the Planets, whence we conclude, that they ſhine by their own Light as the Sun does. And indeed they are [1] at ſo great a Diſtance from the Sun, that we are ſure they could not be ſeen at all, if they borrowed their Light from him, any more than we can ſee the Satellites of *Jupiter*, and the ſmall Star about *Saturn*, without good Teleſcopes.

4. This

[1] *At ſo great a Diſtance from the Sun,* &c.) That the fixed Stars are at an immenſe and inconceivable Diſtance from us, may eaſily be collected from hence; that though by the Earth's annual Motion, we are nearer them by the whole Length of the Diameter of the *magnus Orbis*, yet their Situation or Magnitude (which indeed is but like a Point. See *the Notes on Chap.* xxxii. *Art.* 26. *of this Part.*) is not in the leaſt altered. And indeed it cannot be determin'd how great this Diſtance is; becauſe there is no Parallax nor any other Method, whereby it can certainly be found out. Mr. *Hugens* thought of a very ingenious Way of making a Conjecture about it in his *Conjectures concerning the Planetary Worlds. Book* 2. *Pag.* 125. Thoſe, ſays he, *that have hitherto undertook to calculate their Diſtance, have not been able perfectly to compaſs their Deſign, by reaſon of the extreme Niceneſs, and almoſt Impoſſibility of the Obſervations requiſite for their Purpoſe. The only Method that I ſee remaining to come at any tolerable Probability in ſo difficult a Caſe, I ſhall here make uſe of. Seeing then that the Stars, as I ſaid before, are ſo many Suns, if we do but ſuppoſe one of them equal to ours, it will follow, that its Diſtance from us, is as much greater than that of the Sun, as its apparent Diameter is leſs than the Diameter of the Sun. But the Stars, even thoſe of the firſt Magnitude, though viewed through a Teleſcope are ſo very ſmall, that they ſeem only like ſo many ſhining Points, without any perceivable Breadth, ſo that* ſuch

4. This being ſo, it is reaſonable to think that the fixed Stars are ſo many Suns, placed in different Parts of the World:

4. That the fixed Stars differ in nothing from the Sun.

ſuch Obſervations can here do us no good. When I ſaw this would not ſucceed, I ſtudied by what Way I could ſo leſſen the Diameter of the Sun, as to make it not appear larger than the Dog, or any other of the chief Stars. To this purpoſe I cloſed one End of my twelve Foot Tube with a very thin Plate, in the Middle of which I made a Hole not exceeding the twelfth Part of a Line, that is, the Hundred and forty fourth Part of an Inch. That End I turned to the Sun, placing my Eye at the other, and I could ſee ſo much of the Sun, as was in Diameter about the 182*d Part of the Whole. But ſtill that little Piece of him was brighter much than the Dog-Star is in the cleareſt Night. I ſaw that this would not do, but that I muſt leſſen the Diameter of the Sun a great deal more. I made then ſuch another Hole in a Plate, and againſt it I placed a little round Glaſs that I had made uſe of in my Microſcopes, of much about the ſame Diameter with the former Hole. Then looking again towards the Sun, (taking care that no Light might come near my Eye to hinder my Obſervation) I found it appear of much the ſame Clearneſs as* Sirius. *But computing according to the Rules of* Dioptricks, *I found his Diameter now was but* $\frac{1}{152}$ *part of that hundred and eighty ſecond Part of his whole Diameter that I ſaw thorough the former Hole. Multiplying* $\frac{1}{152}$ *and* $\frac{1}{182}$ *into one another, the Product I found to be* $\frac{1}{27664}$. *The Sun therefore being Contracted into ſuch a Compaſs, or being removed ſo far from us (for it's the ſame thing) as to make his Diameter but the* 27664*th Part of that we every Day ſee, will ſend us juſt the ſame Light as the Dog-Star now doth. And his Diſtance then from us will be to his preſent Diſtance undoubtedly as* 27664 *is to* 1; *and his Diameter little above four Thirds* 4‴. *Seeing then* Sirius *is ſuppoſed equal to the Sun, it follows that his Diameter is likewiſe* 4‴, *and that his Diſtance to the Diſtance of the Sun from us is as* 27664 *to* 1. *And what an incredible Diſtance that is, will appear by the ſame Way of Reaſoning that we uſed in meaſuring that of the Sun. For if twenty five Years are required for a Bullet out of a Cannon, with its utmoſt Swiftneſs, to travel from the Sun to us, then by multiplying the Number* 27664 *into* 25, *we ſhall find that ſuch a Bullet would ſpend almoſt ſeven hundred thouſand Years, in its Journey between us and the neareſt of the fixed Stars. And yet when in a clear Night we look upon them, we cannot think them above ſome few Miles over our Heads. What I have here inquired into is concerning the neareſt of them. For the other; ſince, as was before obſerved, they are ſo much farther removed into the Heavens, that the Diſtance of the neareſt from the following ones, is as great as the Diſtance of thoſe from the Sun, what an immenſity muſt there ſtill remain ——— When I have been reflecting thus with my ſelf, I thought all our Arithmetick was nothing, and that we are verſed but in the very Rudiments of Numbers in Compariſon of this great Sum.* This is indeed a very ingenious Conjecture of Mr. *Hugens*. But our *Flamſtead* has at laſt found, by wonderful diligent Obſervations, that the fixed Stars have an annual Parallax, which is a compleat Demonſtration of the Motion of the Earth. And that this Parallax is about 30″.

But the following Particulars, which are worth Obſervation, are ſo many Conſequences of the vaſt Diſtance of the fixed Stars.

Firſt, If we were to approach ninety nine Times nearer to the fixed Stars than we now are, ſo that we were diſtant from them, but a hundredth Part of the preſent Diſtance, we ſhould ſee them but a very little bigger than we do now; for they would appear no bigger nor no otherwiſe than they do now, when looked at with a Teleſcope which magnifies the Object a hundred Times.

Secondly, Nine Parts at leaſt in Ten of that whole Space which is betwixt us and the fixed Stars, receive no more Light either from the

World: In order therefore to explain the Nature and Properties of them, I ſhall ſatisfy my ſelf, by explaining here the Nature and Properties of the Sun, and the Explication of the one may ſerve for the Explication of the other.

5. What the Body of the Sun is.

5. We have already ſeen, that that Part of the World in the Center of which the Sun is placed, and which reaches every way a great deal beyond Saturn, [1] is a certain Vortex; the Matter of which, except the Earth and Planets, is very liquid and tranſparent. To which we may add, that all this vaſt Extent of Matter, is compoſed of that of the firſt and ſecond Element only, and that it contains a great deal more of the firſt Element than is neceſſary to fill up all the Interſtices that there muſt be between the Parts

Sun or from any of the fixed Stars, than we do from the Stars in a clear Night.

Thirdly, Light (becauſe, as was ſhewn above in *the Notes on Part* I. *Chap.* 27. *Art.* 30. it is propagated from the Sun to the Earth in about ſeven Minutes of Time) cannot come from the fixed Stars to us in leſs than forty Days time at the leaſt; and Sound could not come from thence to us in leſs Time than fifty thouſand Years; and a Ball ſhot out of a Cannon, would take up much longer Time ſtill. *See the Philoſophical Tranſactions.* No 209.

And from hence the famous Mr. *Whiſton* draws a very Ingenious Argument which overthrows both the Ptolemaick and Tychonick Syſtems of the World: 'If, *ſays he*, there 'be any Difference in the Diſtances 'of the fixed Stars from us, and none 'of the Ptolemaick Aſtronomers have 'ventured peremptorily to affirm 'that there is not; then by reaſon of 'their vaſt Diſtances, the Time 'which Light takes up in coming 'from a fixed Star to the Earth, muſt 'be very great, not to be meaſured 'by a few Hours or Days, but by 'whole Weeks or rather Months. 'Whence it will follow, that the 'true Places of the fixed Stars, tho' 'they are both really and apparently 'in their proper Parallels of Declina-'tion; yet with reſpect to their right 'Aſcenſions, will very much differ 'from their apparent Places, nor will 'any one of them, unleſs by great 'Chance, ever be in that Place, with 'reſpect to the Horizon or Meridian 'of the Earth where it appears to be. 'And beſides it will follow from the 'Difference of Diſtances, that the 'real Order and Situation of the fixed 'Stars with regard to each other, is 'not ſuch as we ſee it from the Earth. 'We do indeed certainly know by 'Obſervation, the particular Parallel 'which any of them is in, becauſe the 'ſucceſſive Propagation of Light does 'not at all diſturb their Situation 'ſideways; but what their Places are, 'with reſpect to each other in any 'Parallel, cannot at all be known by 'Obſervation, unleſs we knew their 'Diſtances, and conſidered well what 'Time Light would take to paſs 'through them (which at preſent we 'do not.) Now ſince we know the 'Places of the fixed Stars according 'to their Longitude and Latitude, 'only by having their Places with re-'ſpect to their right Aſcenſion and 'Declination given by Obſervation; 'it will certainly follow, that the 'real Places of the fixed Stars can 'never be at all determined by us, 'the ſucceſſive Motion of Light 'hindering it. Which ſtrange or ra-'ther whimſical thing, in the ancient 'Hypotheſis, has not been obſerved 'by any Body (that I know of) but I 'think it is very well worth the No-'tice of the Followers of *Ptolemy* (if 'there remains any ſuch.) Where-'fore I leave ſo ſtrange and ſo un-'artificial an Invention to be con-'ſider'd by them and to be deſpiſed 'by you.' *Aſtronom. Lect. p.* 233.

1 *Is a certain Vortex*, &c. *See the Notes on Art.* 22. *of this Chapter.*

Parts of the ſecond Element: In Conſequence of this; ſince it is certain that Bodies which move in a Circle, have a Tendency to fly off from the Center of their Motion, and that the groſſeſt and moſt heavy Parts, ſuch as thoſe of the ſecond Element, have a greater Tendency to fly off than the other; it neceſſarily follows, that the Parts of the ſecond Element ought to go off from the common Center and to approach as near to each other, as their Figure and particular Motion will allow: So that they ought to force into the Place which they leave, all the Matter of the firſt Element, except ſo much only as is requiſite to fill up the Intervals between them. It is certain therefore, that towards the Middle of the Vortex in which we dwell, there muſt be a large Quantity of Matter, which is compoſed of the firſt Element only; and it is this Maſs of the ſubtle Matter which poſſeſſes the Center of the Vortex in which we are[1], which we call the Body of the Sun.

6. We

1 *Which we call the Body of the Sun*, &c.) Since we have ſhewn that the ſubtle Matter mentioned *all along above*, and the Vortexes mentioned *below* (in the *Notes on Art.* 20.) are fictitious and contrary to the Nature of Things: Let us hear what the illuſtrious Sir *Iſaac Newton* ſays ſo incomparably well concerning the Nature of the Sun and Stars from other Principles. ' Do ' not great Bodies, *ſays he*, conſerve ' their Heat the longeſt, their Parts ' heating one another; and may ' not great denſe and fixed Bodies, ' when heated beyond a certain ' Degree, emit Light ſo copiouſly ' as by the Emiſſion and Re-action ' of its Light, and the Reflections ' and Refractions of its Rays with- ' in its Pores, to grow ſtill hotter, till ' it comes to a certain Period of ' Heat, ſuch as is that of the Sun; ' And are not the Sun and fixed Stars ' great Earths vehemently hot, whoſe ' Heat is conſerv'd by the greatneſs of ' the Bodies, and the mutual Action ' and Re-action between them and ' the Light which they emit, and ' whoſe Parts are kept from fuming ' away, not only by their Fixity, but ' alſo by the Weight and Denſity of ' the Atmoſpheres incumbent upon ' them, and very ſtrongly compreſ- ' ſing them, and condenſing the ' Vapours and Exhalations which ' ariſe from them? For if Water be ' made lukewarm in any pellucid ' Veſſel, and that Veſſel be afterwards ' emptied of Air, that Water in ' the *Vacuum* will bubble and boil ' as vehemently as it would do if ' heated much hotter in a Veſſel ' ſet on the Fire in the open Air. ' For the Weight of the incum- ' bent Atmoſphere keeps down the ' Vapours, and hinders the Water ' from boiling, untill it grow much ' hotter than is requiſite to make it ' boil in *Vacuo*. Alſo a mixture of Tin ' and Lead being put upon a red hot ' Iron *in vacuo*, emits a Fume and ' Flame; but the ſame Mixture in the ' open Air, by reaſon of the incum- ' bent Atmoſphere, does not ſo much ' as emit any Fume, which can be ' perceived by Sight. In like man- ' ner the great Weight of the Atmo- ' ſphere, which lies upon the Globe of ' the Sun.' (For the Weight of Bodies upon the Superficies of the Sun, is to the Weight of Bodies upon the Superficies of the Earth, as the Magnitude and Denſity of the Sun is to the Magnitude and Denſity of the Earth,) ' may hinder Bodies there from riſing ' up and going away from the Sun in ' the Form of Vapours and Fumes, un- ' leſs by Means of a far greater Heat ' than that which on the Surface of ' our

6. That every Section of the Sun which is parallel to the Ecliptick, is round.

6. We certainly find in this Mass of subtle Matter, the same Properties which Experience shews us, that there are in the Sun. For first, This Mass of subtle Matter, or this very liquid Body, which we may compare to the finest Flame, must necessarily be round which Way soever it be turned about; that is, if it be cut by any Plane parallel to the Ecliptick, in what Part soever the Section be made, it must always be a Circle, otherwise it would follow, that there were Particles of the second Element, that were not got so far from the Center of the Circle which they describe, as they ought to be, but this is impossible, because the Heavens are fluid.

7. Whilst some of the Matter goes off by the Ecliptick; other Matter enters in by the Poles.

7. Further; because there is always a large Quantity of the Matter of this first Element, which endeavours to go off from the Center of the Vortex, and which does indeed go off from thence through the Interstices which there is between the Particles of the second Element; it always endeavours to go off in Planes parallel to the Ecliptick, and never tends to the Poles. But because the World is full, the Matter which goes thus off from the Sun, forces other Matter to enter by the Poles.

8. That the Poles of the Sun or of any fixed Star are placed directly against the Ecliptick of some other fixed Star.

8. Because we consider all the fixed Stars as so many Suns, which consequently ought every one of them to have their own proper Poles and Eclipticks, from which the Matter ought to flow in the Manner just now described; it is reasonable to think, that that Matter which flies off from the Places near the Ecliptick of one Star, enters in by the Poles of another Star, which is confirmed from hence, that we cannot conceive how a great Number of Vortexes could subsist long together, without destroying each other, and being all blended into one, if the Poles of some did not directly correspond to the Eclipticks of others.

'our Earth would very easily turn 'them into Vapours and Fumes. And 'the same great weight may condense 'those Vapours and Exhalations as 'soon as they shall at any time begin 'to ascend from the Sun, and make 'them presently fall back again into 'him, and by that Action increase 'his Heat; much after the manner, 'that on our Earth the Air increases 'the Heat of a culinary Fire. And 'the same Weight may hinder the 'Globe of the Sun from being diminished, unless perhaps by the Emission of Light, and a very small 'Quantity of Vapours and Exhalations. *Newt. Opt. pag.* 318.

9. Now

9. Now the Matter of the firſt Element which enters into a Star at one of its Poles, goes on in a ſtraight Line, till it meets with the Particles of the ſecond Element which are on the Side of the oppoſite Pole, againſt which ſtriking and preſſing with all the Force and Impetus of its Motion, it is reflected, and then turned round in Planes perpendicular to the Ecliptick; and being moved every Way and on all Sides, it puſhes away the Particles of the ſecond Element, which were got nearer than the reſt to the Center of the Star which they incompaſs; and conſequently it muſt by this Means become round, not only at the Poles and the Ecliptick, but on every other Side of the whole Maſs: It follows therefore, that the Sun is an exact and perfect Globe.

9. That the Sun is a round Body.

10. We ſee alſo, that the Sun ought to be luminous, becauſe the Matter of which it is compoſed, by puſhing all round, adds to the ſeveral Motions which they had before to make them a liquid Body, ſuch an Impreſſion as is requiſite to make them, when they fall upon the Bottom of the Eye, ſhake the Extremities of the ſmall Nerves which are there, and ſo cauſe the Senſation of Light.

10. Why the Sun is light.

11. It is eaſy to collect from hence, that the Sun is *virtually* hot, that is, that it has a Power to excite the Senſation of Heat in us: For it was before ſhewn, that this Power neceſſarily accompanies that of Light, and is proportionable to it; ſo that the Sun being very luminous, it muſt alſo be very hot.

11. Why the Sun is hot.

12. It may be obſerved here, that ſome of the Particles of which the Sun is compoſed may ſo meet together and be entangled with each other ſometimes, that though they continue in Motion with reſpect to the Particles of the ſecond Element, with which they are ſurrounded; yet with reſpect to each other they are at reſt, and ſo compoſe an opake Body, like the Froth formed upon the Surface of Liquors when they begin to boil: And this may ſerve to account for thoſe Spots which we often ſee, by the Help of Teleſcopes, upon the Body of the Sun.

12. How the Spots in the Sun are formed.

13. It is alſo obſervable with regard to theſe Spots, that we never ſee any of them, but near the Ecliptick; becauſe, though any one of them ſhould begin to be formed near the Poles, as ſoon as it becomes pretty large, it muſt be forced to quit thoſe Places, and retire towards the Ecliptick; for the Matter which deſcends from the Heavens, and enters in at the Poles of the Stars, will puſh it and drive it that Way; and according to the Laws of Motion, the Tendency which it has to go off from the Center of the

13 Why they never appear, but near the Ecliptick.

Circle which it defcribes, will caufe it to approach the Ecliptick as the moft remote Place.

14. Why the Light of the Sun is weakned fometimes for fome Months together.

14. And it may fo happen, that fuch a Number of thefe Spots may be formed, and they may be fo ftopped by each other, as to cover almoft the whole Body of the Sun: And this agrees with what we read in fome Hiftorians, [1] that the Sun has fometimes appeared with a very faint Light for a whole Year together, fo that Men might look fteadily upon it without dazling their Eyes.

15. That this Weaknefs of the Sun's Light is not to be afcribed to the Clouds, and that the fixed Stars do not receive their Light from the Sun.

15. And becaufe, during this Time, the fixed Stars did not appear lefs luminous than ufual; it is manifeft that the Weaknefs of the Sun's Light cannot be imputed to any Vapours or Exhalations in the Air; for if it had been fo, the Stars would have been hindred from fhining likewife. And this fhews us alfo, that the fixed Stars do not borrow their Light from the Sun; for if they did, they would not have appeared fo bright as ufual.

16. How the Spots of the Sun may difappear.

16. The Comparifon which we juft now made between the Spots of the Sun, and the Froth which gathers together upon the Surface of Liquors when they begin to boil, give us Ground to think that they may be diffipated in Length of Time as Froth is; either becaufe the liquid Matter of the Sun, which is in a very quick Motion, and agitated to the higheft Degree, begins to difunite the Bottom Parts of the Spots, whofe Particles were ftopped by each other; or becaufe this Matter gets over the Spot which fwims upon the Surface, in the fame Manner as boiling Liquor rifes up and flides over the Froth, and at laft finks it to the Bottom of the Veffel.

17. Why the Sun appears brighter in that Place where the Spot was a little before.

17. It may be obferved alfo, that if any of thefe Spots difappear in this manner, the Liquid Matter which paffes or flides over it, and whofe Paffage is thereby ftraightned, and its Motion accelerated, muft prefs upon and pufh forward more than ufually, the Particles of the Second Element which are againft this Place, and fo caufe us to perceive a brighter Light there, than in any other Part of the Sun's Surface; and this is confirmed by Obfervation: For it fometimes has happened, that upon the

1. *That the Sun has fometimes appeared, &c.*] Pliny Book II. Chap. 30. *There have been prodigious and very long Eclipfes of the Sun, as when* Cæfar *the Dictator was killed, and at the Time of the War with* Mark Anthony; *it being pale for almoft a whole Year together.* And *Plutarch,* Of the Opinions of the Philofophers. Xenophanes *writes of an Eclipfe of the Sun for a whole Month.*

difappearing of a Spot feen in the Sun's Body one Day, an extraordinary Flame hath been feen to fucceed it the next Day.

18. How thefe Spots may appear all on a fudden.

18. It is alfo reafonable to think, that fome of thefe Spots may be fo thick and denfe, as to require a very long Time to diffolve them intirely; they may therefore rife up again to the Surface of the Fluid in which they were immerfed, and be immerfed in it again afterwards, before they are wholly diffipated: So that we need not be furprifed when we fee fome of the Spots upon the Sun's Body difappear and appear again, in lefs Time than we can can conceive them to be entirely diffipated, and new ones formed.

19. How fome fixed Stars may difappear and new ones appear.

19. If the fixed Stars are liable to the fame Alterations, fince they are at vaftly greater Diftance from us than the Sun; it is eafy to imagine that they may entirely ceafe to be feen, when under fome Circumftances, in which the Sun would appear only lefs luminous. Whence it is not at all wonderful, that we fhould now fee fome fixed Stars in the Heavens, which the Antients could not fee; and that they obferved fome in their Time, which we cannot find now: Nor was there any Wonder in that famous Star which was firft feen about the 10th of *November* in the Year 1572. amongft the Stars in the Conftellation called *Caffiopeia* [1] which appeared all on a fudden larger and brighter than any other fixed Star; but afterwards grew lefs and weaker, till at laft it wholly difap-

1 *Which appeared all on a fudden, &c.*] The Appearance of new Stars is much better accounted for from the Theory of Comets. For tho' fome of the fixed Stars may be fo very remote from us as not to be feen by the Help of our beft Glaffes, yet as they are fiery Bodies like the Sun, if any new Matter or fewel be added to them, they may on a fudden blaze out fo as to be feen by the naked Eye, brighter than any other Star; and as this fewel is devoured, they may diminifh in their Brightnefs, and by Degrees return to their firft invifible State. And that Comets might probably fupply them with this Fewel, See Sir *Ifaac Newton's Princip. Book* III. *pag.* 481. 'The Comet which appeared in '1680 in its Perihelion, was not fo 'far diftant from the Sun, as the 'fixth Part of the Sun's Diameter, 'and by reafon of its very great Velocity in this nearnefs, and fome 'Denfity that there is in the Sun's 'Atmofphere, it muft meet with 'fome Refiftance, and be a little retarded and approach nearer the Sun; 'and by approaching in this manner 'nearer and nearer to the Sun every 'Revolution, it muft at laft fall into 'the Body of the Sun. And in its 'Aphelion, where it moves floweft, 'it may fometimes be retarded by the 'Attraction of other Comets, and at 'fome time or other fall into the 'Sun. And fo the fixed Stars likewife, which by Degrees wafte them'felves by fending forth Light and 'Vapours, may be fupplied by Co'mets falling into them, and by the 'kindling of this new Fewel in 'them, they may be taken for new 'Stars.

peared in *March* 1574. without having at all changed its Situation which it had at firſt, with regard to the fixed Stars which were round about it.

20. That the Sun is not exactly in the Center of his Vortex.

20. From what has been hitherto ſaid, it follows, that the Sun ought to be placed in the Center of that irregular Space, which is poſſeſſed by his Vortex, amongſt the many other Vortexes, which have fixed Stars in the Centers of them. But if we conſider that the Matter of the firſt Element which flows out of one Vortex into another, may not be determined to go directly to the Center of this other, we may conclude, that the Star in one Vortex ought to be in the Middle between the Center of the Vortex, and the Place which the Matter of the firſt Element, ſent out of other Vortexes, tends to.

21. The Cauſe of the Sun's Apogeum.

21. This being ſo; all the cæleſtial Matter which turns about a Star, will be ſtraightened and forced into a narrower Channel in ſome Places than in others, and by this Means, the Circles which are deſcribed by different Portions of this Matter, will be excentrick with reſpect to the Star about which they move; and this is the Reaſon why the Earth does not always move at equal Diſtances from the Sun. Beſides, as Chaff and Pieces of Wood, ſwimming upon the Surface of Water that turns round, do not always deſcribe the ſame Circle, but deſcribe Circles ſometimes nearer and ſometimes further off the Center of the Vortex, ſo in like manner the Earth in turning about the Sun, does not always neceſſarily deſcribe the ſame Circle: And hence it is, that the greateſt Diſtance betwixt the Earth and the Sun, or its *Apogeum* may alter in different Ages, and be obſerved ſometimes in one Part of the Firmament and ſometimes in another.

22. The Reaſon why the Earth's Axis keeps always parallel to it ſelf.

22. In order to explain the whole apparent Motion of the Heavens, there remains nothing but to find out the Cauſe, why the Earth in its annual Motion about the Sun is carried in ſuch a manner, that its Axis always continues parallel to its ſelf, or which is the ſame thing, its Poles always are directed to very nearly the ſame Points in the ſtarry Heaven. But this will not be very difficult to account for, if we conſider, that the diurnal Motion of the whole Maſs compoſed of Earth, Water, and Air determines the ſubtle Matter, which is in continual Agitation in the inward Parts of the Earth, to retire from its Axis, and go off in Planes parallel to the Equator; and that at the ſame time there muſt neceſſarily enter into thoſe Parts which are near the Poles, a like Quantity

of

of the ſame ſort of Matter flowing from the Parts near the Ecliptick of ſome neighbouring Vortex: For it is eaſy to conclude from hence, that when the Earth has once begun to receive the Matter which comes from one particular Part of the Heavens, it will continue to receive it more conveniently, than it will do any other Matter that comes from other Parts; becauſe its Pores are more fitted to receive it, and it can enter into them without Interruption: Wherefore theſe occult Pores which we conceive to be parallel to the Earth's diurnal Motion, muſt neceſſarily be ſo placed, [1] that the Matter which enters into them, muſt enter directly in; which if it does, the Poles of the Earth muſt always be directed to the ſame Parts of the Heaven, and conſequently its Axis keep always parallel to itſelf.

23. In

1 *That the Matter which enters, &c.*] That the Vortexes of Matter in which the Planets ſwim, are mere Fictions and contrary to the Phænomena of Nature; is evident from the following Arguments:

Firſt, The immenſe Space of the World is ſo far from being full of Matter (which imaginary Plenum is the ſole Foundation of the Fiction of Vortexes) that on the contrary, that Space which is fill'd with Matter, bears no Proportion at all, to that immenſe Space which is void of all Matter. *See the Notes on Part* I *Chap*. viii. *Art*. 2.

Secondly, It is evident from the Motion of Comets, which paſs very freely in the heavenly Spaces all Ways and from and to all Parts, (in Orbs which cut the Planets Orbs at all Angles) that the Planets cannot be carried along by Vortexes of Matter.

Thirdly, 'According to the Laws 'of Aſtronomy a Body which re'volves in an *Excentrick Orb*, moves 'ſlower in its *Aphelion*, and quicker 'in its *Perihelion*; but according to 'the Laws of Mechanicks, the 'Matter of the Vortex ought to move 'ſwifter where the Place is ſtraiter 'and more *compreſſed*, that is, in the 'Aphelion, than where the Place is 'wider, *and leſs compreſſed, that is in 'the Perihelion*, which two things 'contradict each other. Thus in the 'beginning of the Sign *Virgo*, where 'the Aphelion of *Mars* now is, the 'Diſtance betwixt the Orbs of *Mars* 'and *Venus*, is to the Diſtance be'tween the ſame Orbs in the begin'ning of the Sign *Piſces* in the Pro'portion of three to two very near'ly: And therefore the Matter of 'the Vortex contained between thoſe 'two Orbs ought to move ſwifter in 'the Beginning of *Piſces*, than in 'the Beginning of *Virgo* in the ſame 'Proportion of three to two; For 'the ſtraiter the Space is, through 'which the ſame Quantity of Mat'ter paſſes in the ſame Time of one 'Revolution, with ſo much the 'greater Velocity ought it to paſs. If 'therefore the Earth were carried 'along in this Cæleſtial Matter, being 'relatively at reſt with it, and revolv'd 'together with it about the Sun; its 'Velocity in the Beginning of *Piſces*, 'would be to its Velocity in the Begin'ning of *Virgo*, in a ſeſquialterate Ra'tio: Whence the apparent diur'nal Motion of the Sun in the begin'ning of *Virgo*, would be more 'than ſeventy Minutes, and in the 'Beginning of *Piſces*, leſs than forty 'eight Minutes. Whereas (we find 'by Experience) the apparent Moti'on of the Sun is greater in the Be'ginning of *Piſces*, than in the Begin'ning of *Virgo*, and therefore the 'Earth moves ſwifter in the Begin'ning of *Virgo* than in the Begin'ning of *Piſces*. The Hypotheſis 'therefore of Vortexes directly con'tradicts the Aſtronomical Phæno'mena, and tends more to confound 'the Cæleſtial Motions than to ex'plain them. *See Newt. Princip*, '*Book* II. *Schol*. 10. *Prop*. LIII.

Fourthly,

23. That the Planets are not exact Spherical Bodies.

23. In order to conclude my Opinion concerning the Nature of the Planets, in few Words; we may add to what has been already said of their being spherical Bodies, which

Fourthly. 'If three equal round 'Vessels be filled, the one with Water, the other with Oil, the third 'with molten Pitch, and the Liquors 'be stirred about alike to give them 'a vortical Motion; the Pitch by its 'Tenacity will lose its Motion quickly; the Oil being less tenacious 'will keep it longer, and the Water 'being less tenacious will keep it 'longest, but yet will lose it in a 'short time. Whence it is easy to 'understand, that if many contiguous 'Vortices of molten Pitch, were each 'of them as large as those which 'some suppose to revolve about the 'Sun and fixed Stars, yet these and all 'their Parts, would, by their Tenacity 'and Stiffness, communicate their 'Motion to one another, till they all 'rested among themselves. Vortices 'of Oil or Water, or some fluider 'Matter, might continue longer in 'Motion; but unless the Matter were 'void of all Tenacity and Attrition 'of Parts, and Communication of 'Motion (which is not to be supposed) the Motion would constantly 'decay,' *Opticks, pag.* 374.

It is evident therefore that the Planets are not carried along in Vortexes of Matter as in a River. But it now appears from the most exact Observations of the Phænomena of the cœlestial Motions, that they are so placed in the most free and open Spaces, as to revolve about certain Centers by a Force compounded of *Gravity* and a *Projectile Motion in straight Lines*, which were impressed upon them by God at the Beginning; *viz.* the larger Planets about the Sun, and the Satellites or Moons about their own Planets; I shall explain the Whole of this in a few Words.

Because all Matter gravitates towards all Matter, in a certain Proportion to the Quantity and Distance (See *the Notes on Chap.* 28. *of this Part.*) And because the Body of the Sun is much larger than all the Planets put together; it is manifest that if all the Planets were at rest in their proper Places, they would by their own Gravity be carried directly into the Sun,

Now because the Case was thus, and all the Planets *gravitated* towards the Sun, God impressed upon them *a projectile Motion in straight Lines* also; in such a manner as to be perpetually pull'd from these straight Lines and kept from flying off from their Orbs by Gravitation, and at the same Time to be perpetually urged on by that *projectile Motion*, lest they should fall into the Sun by the Force of their Gravitation: So that by these two Forces acting together, they must necessarily be carried in some curved Line about the Sun; just as a Stone turned about in a Sling, by being perpetually hindred by the String from flying off, all the while that it endeavours to recede from the Center by its projectile Motion, describes a Circle.

This will be plainer by looking on the Scheme. Let S be the Sun, A a Planet; and in the first Moment of Time, let A describe by its projectile Motion, the right Line AB; in the second Moment of Time, if nothing hindred it, it would go on straight to c, and describe the Line Bc equal to AB. But when it comes to B it is pulled by its Gravity, and made to decline from the straight Line Bc, and to go in the straight Line BC. So likewise when it comes to C, it is pulled by its Gravity and made to decline from the straight Line Cd, and to go in the straight Line CD. Now if the Number of the Triangles ASB, BSC, CSD, be infinitely increased, and their Breadth infinitely diminished, their last Perimeter ABCDEF will be a curve Line; and so the Gravity by which the Planet is pulled from the Tangent of the Orb, will act continually, and the Planet will also be carried in this curve Line about the Sun.

Tab. XVIII. Fig. 1.

If the *projectile* Velocity be so exactly adjusted to the *gravitating Force* as to balance each other in such a Manner that the Planet shall neither approach nearer to, nor recede further from the Sun; in this Case the Planet will describe an exact Circle about

which ſhine by the Light they receive from the Sun; that their Superficies cannot but be unequal like that of the Earth,

about the Sun; that is, if S be ſuppoſed the Center, and S B the Radius of a Circle, B S C the Angle generated in a Moment of Time, B c or B C the Tangent, Arch or Sine of this Angle, and Cc the verſed Sine of double this Angle; then if Bc or BC repreſent the *projectile* Velocity, Cc will repreſent the *gravitating* Force: And becauſe (by the Property of the Circle) $Cc = \frac{CB2}{SB}$: Tab. XVIII. Fig. 1. Therefore the *gravitating* Force neceſſary to make Bodies revolve in concentrick Circles with an equable Motion, muſt be as the Squares of their *projectile* Velocities, applied to the Radius's of the Circles; or the *gravitating* Forces muſt be in a duplicate Ratio of the *projectile* Velocities directly, and a ſimple Ratio of their Radius's inverſely. And if S B be given, that is, if a Planet revolves in the ſame or equal Circles with different projectile Velocities, the *gravitating* Forces muſt be as the Squares of thoſe Velocities.

Corol. 1. And becauſe the periodical Times are in a Ratio compounded of the Ratio of their Radius's directly, and the Ratio of their Velocities inverſely, theſe being ſubſtituted for each other in the Ratio $\frac{CB2}{SB}$; the centripetal Forces will be in a Ratio compounded of the Ratio of the Radius's directly, and the Ratio of the Squares of their periodical Times inverſely.

Corol. 2. And hence it will alſo follow; that if the Periodical Times be in a ſeſquialterate Ratio of the Radius's (that is, the Squares of the periodical Times as the Cubes of the Radius's) and for that Reaſon, the Velocities reciprocally in a ſub-duplicate Ratio of the Radius's, the Centripetal Forces will be reciprocally as the Squares of the Radius's. See *Newt. Princip. Book* I. *Prop.* iv. *Cor.* 2. *and* 6.

It appears by Obſervation that in the Revolutions of the Planets about the Sun, and the Satellites about the Planets, that the Squares of their periodical Times are as the Cubes of their Diſtances; the gravitating Force therefore by which they are retained in their Orbs, is every where reciprocally as the Square of their Diſtances.

And the ſame holds true, if they are moved in any Conick Section; becauſe there is ſuch an Affinity betwixt a Circle and theſe Sections; a Circle may be made to paſs into an Ellipſis, and an Ellipſis into a Parabola, and a Parabola into an Hyperbola; and as by the Property of the Circle $\frac{BC^2}{Cc}$ is equal to the Diameter, ſo Tab. XVIII. Fig. 1. in all the other Sections the ſame Quantity is equal to the *Latus Rectum*: Wherefore if the projectile Velocity with which the Body departs from B be ſuch, that in the ſame Moment of Time that it deſcribes the Line Bc, the centripetal Force cauſes it to move through the Space Cc, the Body will move in ſome of the Conick Sections whoſe *Latus Rectum* will be equal to $\frac{BC^2}{Cc}$: And they will be of different Species according to the different projectile Velocities, and the different directions of them. See *Princip. Book* I. *Prop.* xiii. *Corol.* 2.

Hence it follows; that becauſe the Motion of a Planet is retarded as it recedes from the Sun, and accelerated as it approaches towards the Sun, the Planet always *deſcribes equal Areas in equal Times.* That is if the Planet by moving from R to F in the Space of an Hour, deſcribes the Triangle R A F by Rays drawn to the Sun; Tab. XVIII. Fig. 2. the ſame Planet in the ſame Space of Time, will move in ſuch a manner from F to L, or from L to O, or from O to M, or from N to P, that the Triangles F A L, L A O, O A M, N A P, will be equal to each other, and to the Triangle R A F.

This noble Propoſition may alſo be demonſtrated in the following Manner. Let Cc be drawn parallel to the Line S B; then becauſe the Lines Cc and S B are parallel; Tab. XVIII. Fig. 1. the Triangle S C B will be equal to the Triangle ScB, and alſo equal

Earth, becauſe every Part of them is viſible, viewed every Way. I know that my Opinion in this Matter, is widely different from that of a great many Philoſophers, who think that they ought to aſcribe all poſſible Perfections to every Thing that is contained in the Heavens; and becauſe they believe that an exact ſpherical Figure is in its ſelf a real Perfection, they therefore affirm, that the Planets are perfectly round. But I freely depart from an Opinion which has no Foundation to ſupport it, and from which it would follow, that the Planets would be viſible only in a very ſmall Part of their Superficies: For upon this Suppoſition, all the other Parts of them would neceſſarily reflect the Light another Way, ſo that it could not come at the Eye. Beſides, this pretended Smoothneſs of the Superficies of the Planets does not agree with Experience. Thus, for Inſtance, we can ſee with a Teleſcope towards the Edge of the Light which falls upon the Body of the Moon, certain dark or obſcure Inequalities, which look like Shadows made in the Valleys by Mountains, and which leſſen, and at laſt quite diſappear, according as the Sun ſhines more or leſs directly upon thoſe Places: And theſe different dark or obſcure Places, (ſome of which certainly proceed from hence, that there are ſome Parts of the Moon which do not reflect ſo much Light as others) have given Occaſion to a great many People, when they look upon the Moon, to imagine that they ſee *Eyes*, *a Noſe*, *and Mouth*, *&c.* But we ſee nothing like them when we look through a Teleſcope.

equal to the Triangle, S B A: That is, becauſe A B, B C and C D are Lines moved through in equal Times (by the Hypotheſis) the equal Triangles A S B, BSC, *&c.* will be equal Areas deſcribed in equal Times. See *Newt. Princip. Book* I. *Sect.* ii. *Prop.* 1.

This is the Nature of the Motion of all the Planets, as well the primary Planets about the Sun, as the Moons or Satellites about their own Planets; except only that they are moved in Ellipſes not much different from Circles.

But the projectile Motion may be ſo very quick, that the Ellipſis in which the Planet is carried may become of a very great Length and very excentrick; ſuch as is here deſcribed. And a Planet moving in ſuch an Orb is called a *Comet*.

Tab. XVIII. Fig. 3.

Nay, the projectile Motion may poſſibly be ſo much quicker ſtill, that the Planet may be carried in a Parabola, ſo as never to return again: But we do not know of any ſuch Motion in Nature.

Upon theſe Principles the illuſtrious Sir *Iſaac Newton*, in his wonderful Book of the *Mathematical Principles of Philoſophy*, has explained the true Syſtem of the World, and ſhewn the true and adequate Cauſes of all the cæleſtial Motions almoſt beyond the Genius of a Man.

And in this, the Sagacity of *Kepler* is very wonderful, who though he could not demonſtrate the Cauſes of the cæleſtial Motions; yet he hit off the true Principles by a ſurpriſingly happy Conjecture. See *Kepler's Introduction* to the Book *Of the Motion of Mars.*

24. All these things being so; we cannot but think that [1] the Planets are very like our Earth; which would not appear otherwise to a Man that should look at

24. *That all the Planets are like our Earth.*

1 *The Planets are very like our Earth,* &c.] Amongst the Ancients, 'Heraclides and the *Pythagoreans* (according to the Testimony of *Plutarch*, Book II. Chap. 13. concerning the Opinions of the Philosophers) thought that every Star was a World, having Æther and Air surrounding their Earth, but especially the Moon, which has in it a great many Mountains, Cities and Houses.' Almost all the rest of them, thought that all the Stars were of a fiery Nature. But it appears now, that the Planets are all of them opake terrestrial Bodies, but some of them more dense than the Earth, for the Density of the Planets are reciprocally as their Distances from the Sun, multiplied by the Roots of their apparent Diameters seen from the Sun. *Saturn* therefore is much rarer than the Earth, and *Mercury* much denser; and the Density of the Moon to that of the Earth, is very nearly as 700. to 387. *Newt. Princip. Book* III. *Prop.* 8. *Cor.* 5. *and Prop.* 37. *Cor.* 3. *The Body of the Moon therefore is denser and more terrestrial than our Earth.* I wonder this should escape the learned Mr. *Le Clerc*, who concludes the contrary from the same Principles. *The Moon is not only less than the Earth, about which it moves, but consists also of Matter less dense, from the Principle so often mentioned already, that the most dense Things are the heaviest, that is, get the nearest of all to the Center, about which they move.* Natural Philos. Book I. Chap. 8. Sect. 22.

But *Galilæus* speaks very well of the Similitude which there is between the Planets and the Earth, in his System of the World, *Dial.* I. 'Whether, *says he*, there be any Herbs, Plants or Animals like ours growing in the Moon or any other Planet, or whether there be any Rain or Wind, or Lightning produced there, as there is upon the Earth, I neither know nor believe; much less that there are Men dwelling there. But however I don't see how it necessarily follows, that because there grows nothing there like any of the Things here; therefore there can be no Alteration made there at all, nor no other Things altered, generated, and dissolved, which are not only different from ours, but such as we cannot have the least Notion of at all, nor so much as think about. For as I don't doubt but that if a Person were born and brought up in a large Wood, amongst wild Beasts and Birds, and had never known any thing of the Element of Water, it would never have entered into his Imagination to think, that there was in Nature a World different from the Land, full of Animals which could move very swiftly without Legs or Wings, and that not upon the Superficies only, as Beasts do upon the Ground, but at the very Bottom of all, and not only so, but they can stand still in any Place, which is more than Birds can do in the Air. Nay further, that Men dwell there and build Palaces and Cities; and that they have so quick a Method of Travelling, that they can without any Pains remove their whole Families, Houses and the very Cities themselves into the most distant Countries; as I say it is very certain, that such a Person, though he had never so quick an Imagination, would never think of *Fishes*, of the *Ocean*, of *Ships*, and *Fleets*; so it may equally, nay much more probably be, that in the Moon, which is at so great a Distance from us, and the Matter of which may perhaps be so very different from that of our Earth, there may exist some Beings, who may act in a Manner which we can have no Notion of, and intirely different from us, as having no Resemblance at all to us, and therefore such as can in no wise enter into our Thoughts.' *See also Hugenius's Planetary Worlds. Book* I.

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it from the Moon[2] than the Moon does to a Man who beholds it from the Earth. Not that I would venture to affirm,

2 *Than the Moon does to a Man*, &c.] Besides the Similitude that there is betwixt the Planets and our Earth, with respect to the Bodies of them, and the Things contained in them; there is also another Similitude between them with regard to external Things, *viz.* the Phænomena of the cœlestial Motions, and the mutual Aspects of the Planets observed from thence. Which Subject *Hugenius in his Planetary Worlds, Book* II. having treated very pleasantly and very astronomically, we will here pick a few Things out of him, and will suppose, that there are some rational Creatures in every one of the Planets, capable of observing the Motions and Phænomena of the Heavens from thence.

'To begin then, *says he*, with the 'innermost and nearest the Sun; we 'know that *Mercury* is three Times 'nearer that vast Body of Light 'than we are; whence it follows, 'that they see him three times bigger and feel him nine times hotter 'than we do. Such a Degree of 'Heat would be intolerable to us, 'and set on fire all our dried Herbs, 'our Hay and Straw that we use. 'And yet there is no doubt but that 'the Animals there, are made of 'such a Temper, as to be but moderately warm, and the Planets such 'as to be able to endure the Heat. 'The Inhabitants of *Mercury*, 'tis 'likely, have the same Opinion of us 'that we have of *Saturn*, that we 'must be intolerably cold, and have 'little or no Light, we are so far from 'the Sun.——The Astronomy of 'those that live in *Mercury*, and the 'Appearance of the Planets to them, 'opposite at certain Times to the Sun, 'may be easily conceived by the 'Scheme of the Copernican System. 'At the Times of these Oppositions, '*Venus* and the Earth must needs 'appear very bright and large to 'them. For if *Venus* shines so gloriously to us when she is but like 'the Moon a little after it is new; 'she must necessarily in Opposition 'to the Sun, when she is full, be at 'least six or seven times larger, and a 'great deal nearer to the Inhabitants 'of *Mercury*, and afford them Light 'so strong and bright, that they have 'no Reason to complain of their 'want of a Moon. What the Length 'of their Days are, or whether they 'have different Seasons in the Year, 'is not yet discovered,——but his 'Year is scarce the fourth Part so 'long as ours.

'The Inhabitants of *Venus* have 'much the same Face of things as 'those in *Mercury*, only they never 'see him in Opposition to the Sun, 'which is occasioned, by his never 'removing above thirty eight Degrees or thereabouts from it. The 'Sun appears to them larger by half 'in his Diameter, and above twice as 'big a Face, as to us, and by Consequence affords them but twice as 'much Light and Heat, so that they 'are nearer our Temperature than '*Mercury*. Their Year is completed 'in seven of our Months and a 'half. In the Night, our Earth, 'when it is on the other Side of the 'Sun from *Venus*, must needs seem 'larger and brighter to *Venus* than 'she ever does to us.

'But *Mars* has some Parts of him 'darker than other some. By the 'constant Returns of which, his 'Nights and Days have been found 'to be of about the same Length 'with ours. But the Inhabitants have 'no perceivable Difference between 'Summer and Winter, the Axis of 'that Planet having very little or no 'Inclination to his Orbit, as has been 'discovered by the Motion of his 'Spots. Our Earth must appear to 'them almost as *Venus* does to us, 'and by the help of a Telescope will 'be found to have its Wane, Increase 'and Full, like the Moon——His 'Light and Heat is twice, and sometimes three times less than ours, 'to which I suppose the Constitution 'of the Inhabitants is answerable.

'In *Jupiter* the Length of their 'Days are equal only to ten of our 'Hours; but their Years are equal to 'twelve of ours, and they enjoy a 'perpetual Equinox there. The Sun 'appears to them who are upon it 'five

affirm, that there are living Creatures in the Moon, or that they generate in the ſame manner as upon the Earth, becauſe though this be a thing poſſible, yet it is alſo poſſible that it may not be ſo. For in things which cannot be certainly determined by Reaſon, I think it very raſh to perſiſt in an Opinion contrary to the common Notions.

'five times leſs in Diameter, than it 'does to us, and conſequently they 'have but the twenty-fifth Part of 'the Light and Heat that we receive 'from it. But that Light is not ſo 'weak as we may imagine, as is 'plain by the Brightneſs of that Pla-'net in the Night; and alſo from 'hence, that when the Sun is ſo far 'eclipſed to us, as that only a twenty-'fifth Part of his Disk remains un-'covered, he is not ſenſibly darkened. 'But if you have a mind exactly to 'know the Quantity of Light that '*Jupiter* enjoys, you may take a Tube 'of what Length you pleaſe, let 'one End of it be cloſed with a 'Plate of Braſs or any ſuch Thing, 'in the Middle of which there muſt 'be a Hole, whoſe Breadth muſt have 'the ſame Proportion to the Length 'of the Tube, as a Chord of ſix Mi-'nutes bears to the Radius; that is, 'about as one is to five hundred and 'ſeventy; Let the Tube be turned 'ſo to the Sun, that no Light may fall 'upon a white Paper placed at the 'End of it, but what comes through 'the little whole at the other End of 'the Tube. The Rays that come 'through this will repreſent the Sun 'upon the Paper, of the ſame Bright-'neſs that the Inhabitants of *Jupiter* 'ſee it in a clear Day. And if you 'remove the Paper and put your Eye 'in the ſame Place, you will ſee the 'Sun of the ſame Magnitude and 'Brightneſs as you would were you 'in *Jupiter*. If you make the Hole 'twice as little in Diameter, there 'will fall upon the Paper and upon 'the Eye, the ſame Light as *the Inha-'bitants of Saturn* have. And al-'though this Light be but a hun-'dredth Part of ours, yet you ſee 'it makes *Saturn* ſhine tolerably 'bright in a dark Night.' Further, they in *Saturn* can ſee but one of the other Planets, and that is *Jupiter*; ſo likewiſe they in *Jupiter* can ſee only *Saturn*, for the reſt are too near the Sun to be ſeen. The fixed Stars, by Reaſon of their immenſe Diſtance, may be ſeen from *Saturn* and *Jupiter*, in the very ſame manner and in the ſame Figures, and diſtinguiſh'd with the ſame inequality of Light, as we ſee them. It is not to be doubted but that *Saturn* by his five Moons, and *Jupiter* by his four, have a great Advantage above us with our one Moon. But the moſt ſurpriſing Phænomena, muſt neceſſarily be produced by that Ring which we mentioned ſurrounding him. There is alſo a very great Difference betwixt Summer and Winter in *Saturn*, becauſe of the great Inclination of his Axis to the Plane of his Orb, which is thirty one Degrees, whereas ours is but twenty-three Degrees and a half. A Year in *Saturn* is equal to thirty of our Years; but what the Length of the Day is, is not yet found out.

Laſtly, the *Moon* is divided into two Hemiſpheres in ſuch a manner, that they who inhabit one of them, have always a Sight of our Earth, and they who inhabit the other never ſee it at all. They alſo ſee our Earth, much larger than the Moon appears to us (and which is very wonderful) hanging always at the ſame Height above the Horizon as if it never moved, and turning about its Axis in twenty-four Hours, and its Light Increaſing, Full, and Decreaſing every Month. The Moon alſo receives from us fifteen times as much Light as we do from it: The Sun alſo riſes and ſets once in every Month of ours, which makes the Days and Nights very long.

CHAP. XXVI.

Of COMETS.

1. Why we treat of Comets in this Place.

WHEN I gave an Account of the Obſervations of the ſeveral cæleſtial Bodies; I ſhould have mentioned thoſe made from Time to Time about Comets; but I purpoſely forbore this, becauſe I know that they are not, in the common Opinion of Philoſophers, reckoned amongſt the heavenly Bodies; and becauſe I was unwilling to increaſe the Difficulty of the Subject I was handling, by adding a Thing which requires much Attention, and which is but little underſtood hitherto. But now, ſeeing Men have always had a great Curioſity to underſtand the Nature of Comets, I think I ought not ſo far to lay aſide this Matter, as not to ſay at leaſt what is moſt certainly known about it; leaving it to them who ſhall come after, to philoſophiſe in a different Manner, if any new Obſervations that ſhall at any time be made, oblige them to alter our Hypotheſis, or to mend our Opinion.

2. What we mean by a Comet.

2. We mean by *Comets*, certain luminous Bodies, which ſometimes appear amongſt the Stars, and ſeem of different Magnitudes, ſometimes about the Bigneſs of *Mars*, *Jupiter*, and *Saturn*. Their Light is very weak and faint, ſo that when the Sky is moſt clear, they appear no brighter, than *Mars*, *Jupiter*, and *Saturn* do, when it is a little Foggy.

3. Of the Rays which ſeem to come from the Bodies of Comets.

3. The Body of a Comet is uſually attended with certain Rays of Light, which are weaker, the more diſtant they grow, and which always diffuſe themſelves according to a certain Rule, which is well worth obſerving, *viz.* If the Comet be very nearly in Oppoſition to the Sun, theſe Rays diffuſe themſelves equally all round it, and look as if it were ſurrounded with Hair; whereas if it be in any other Poſition with reſpect to the Sun, they always extend themſelves to that Part of the Heavens which is oppoſite to the Sun: Thus if the Sun be Eaſt of the Comet, it will dart its Rays towards the Weſt; if the Sun be Weſt of it, it will dart its Rays towards the Eaſt; and when all its Rays are ſent forth in this manner towards one Side, they will appear of a great Length, ſo as ſometimes to take up almoſt a twelfth Part of the whole Compaſs of the Heavens.

4. There is no certain Rule for determining the Times when any Comets will appear; there are ſometimes a great many Years without any appearing, ſometimes more than one appear in leſs than two Months.

4. Of the Times of the Comets appearing.

5. Neither can the Part of the Heavens where they begin firſt to appear, be determined; ſometimes they are firſt ſeen near the Ecliptick, and at other Times near the Poles of the World.

5. Of the Place where they appear.

6. Nor can we certainly tell how long they will continue to be ſeen; for ſome have appeared only for a few Days, whereas others have been ſeen for ſeveral Months.

6. Of their Continuance.

7. One principal Circumſtance to be obſerved is, that a little before a Comet ceaſes entirely to be ſeen, we ſee its apparent Magnitude diminiſh gradually every Day, and alſo its Light grows weaker and weaker.

7. How they ceaſe to be ſeen.

8. They all ſeem to turn about the Earth every Day from Eaſt to Weſt, and to deſcribe Circles parallel to the Equator very nearly. But beſides this apparent Motion, which is common to all the Stars; they have a Motion in the Heavens, which is peculiar to them, and which has no certain Rule by which it can be determined; for ſometimes they move towards the Eaſt, ſometimes towards the Weſt, and ſometimes towards any other Part.

8. Of the Motion of Comets.

9. The Velocity of this Motion, which is peculiar to them, is not the ſame in all Comets, but very different and unequal; for ſome run through more Degrees in a great Circle than others do: Likewiſe the Velocity of the Motion of the ſame Comet is not the ſame every Day; for the Arches which it deſcribes every Day, are ſometimes bigger and ſometimes leſs; however, they are in ſuch a Manner, that if a great many ſtraight Lines be drawn from the Center of the Earth to the ſeveral Places where the Comet appears every Day at the ſame Hour, they will divide the Tangent which belongs to the Place of the Comet's Orb where it moved ſwifteſt, into very nearly equal Parts.

9. Of their proper Motion.

10. Neither is the Courſe which they take always the ſame; ſome of them run through a much greater Part of the Heavens than others do; but however different a Compaſs in the Heavens they have gone through, there have been none, or at leaſt very few, that have been obſerved to deſcribe more than half a great Circle, that is, to have paſſed through more than half the Heavens.

10. Of the Courſe of the Comets.

11. Of the Beard, Tail, and Hair of Comets.

11. When a Comet darts its Rays the ſame Way that it is carried in the Heavens by its own proper Motion, theſe Rays are called its *Beard*. On the contrary, when they extend themſelves to that Part of the Heavens which is contrary to the Direction of its proper Motion, they are called its *Tail*; and when they diffuſe themſelves equally all round it, they are called its *Hair*. Thus the Comet which appeared lately, about the Beginning of the Month of *December* in the Year 1664, in the Southern Part of the World, and on the Eaſt of which the Sun then was; becauſe it darted its Rays towards the Weſt, the ſame Way that it tended by its own proper Motion, was ſaid to be *bearded*; afterwards when it came to be in Oppoſition to the Sun, it appeared *hairy*; and at laſt the Sun getting Weſt of it, the Rays which extended themſelves towards the Eaſt, ſeemed like a *Tail*. And that Comet which appeared a little after, in the Northern Part of the World, on the Eaſt of which the Sun then was; becauſe it went towards the Eaſt by its own proper Motion; the Rays which darted towards the Weſt compoſed the *Tail* firſt, which it continued to be ſeen with for ſeveral Days, and then approached nearer the Sun, which deprived us of the Sight of it, and it has not appeared ſince.

12. An Improbable Opinion of ſome of the Ancients concerning the Nature of Comets.

12. In order to explain the Nature of Comets, ſome of the Philoſophers which lived before *Ariſtotle*, taught, that the Heavens contained not only thoſe viſible Stars, which Aſtronomers have at all Times endeavoured to find out the Motions of; but that they alſo contained an innumerable Company of others, which are ſo ſmall by Reaſon of their great Diſtance from the Earth, that they cannot be ſeen: They added further, that theſe ſmall Stars had a proper Motion of their own according to all Sorts of Directions imaginable; and that their Periods were finiſhed in very unequal Times. As a Conſequence of this, they affirmed, that a Comet was nothing elſe but a Heap of theſe ſmall Stars got together; that their Meeting thus in a particular Place in the Heavens, was owing to their unequal Motion; that this Meeting together made them viſible; and that they ceaſed to be ſeen, when they were all ſeparated from each other, by continuing to move on with their particular Directions. But this is not at all likely, and has more of Subtlety than Probability in it; not becauſe there are not a ſufficient Number of ſmall Stars

for this Purpofe (for there are more to be feen through a Telefcope, than would compofe fuch a Comet;) but becaufe we cannot conceive how it is poffible for them to meet together in fuch a manner in one Body, in all thofe Places where Comets appear; and chiefly becaufe we can much lefs apprehend the Dependence of the Motion of thefe Stars upon the Pofition of the Sun, fo that according to the various Situation thereof, thefe Stars fhould reprefent fometimes *Hair*, at other Times compofe the *Beard*, or *Tail*, of a Comet.

13. The Opinion of Ariftotle *fhewn to be falfe.*

13. This Opinion was rejected by *Ariftotle*, who affirmed, that Comets were certain Fires caufed by Exhalations raifed out of the Earth, and kindled in the upper Regions of the Air; and he believed that they were a great deal lower than the Moon. But this Opinion has no more Probability in it, than the foregoing one; for befides that it is very unlikely that the Earth fhould furnifh a fufficient Quantity of Vapours to feed fo great a Fire all that Time which a Comet fometimes appears; it would follow if this were fo, that the Light of this Fire is independent of the Sun, and confequently that a Comet might dart its Rays in fuch a manner as not at all to depend upon the Situation it has with refpect to the Sun. But that which entirely overthrows this Opinion of *Ariftotle* is, that Aftronomers who lived about two hundred Years ago, and were defirous to find out the Diftance of the Comets, which appeared in their Time, from the Earth, could not obferve that they had any fenfible *Parallax* at all; which could not be, if Comets were nearer us than the Moon, for the Moon has a fenfible *Parallax*.

14. There is no Reafon to think that Comets are nearer than the Orb of Saturn.

14. We may obferve, that thefe Aftronomers who could not find any Parallax in the Comets, (which fhews that they are at vaft Diftance) contented themfelves with only fhewing, that *Ariftotle*'s Opinion was falfe, who placed them in the Air: And it was fufficient for this Purpofe, to make it appear that they were higher than the Moon. But by their Obfervations and Calculations, we may collect that they are further diftant from the Earth than *Saturn*; wherefore if there can be any other Arguments brought to convince us that they are beyond this Planet, we ought not to make any Difficulty in placing them beyond him.

15. A new Conjecture concerning the Nature of Comets.

15. And this is indeed done by a late eminent Philofopher, who is the firft that has explained the Nature

of the heavenly Bodies, in that excellent Book which he has wrote concerning the *Principles* of Philoſophy: For he being aſſured that there are a great Number of fixed Stars, beſides thoſe that can be diſcovered by us; and thinking that ſome of theſe might quit the Place of the Heavens they were in (as well as ſome of them which were ſeen by the Ancients, but cannot be ſeen now, have probably quitted theirs;) he conjectures, that what we call a Comet, is nothing elſe but one of thoſe Stars, which, being by Degrees covered with Spots all over, ſo as entirely to loſe its Light, could no longer keep its Place amongſt the other Stars, but was carried away by one of their Vortexes, which impreſſed a Motion upon it proportionable to its Bigneſs, and Solidity, by which means it may come very near the Heaven of *Saturn*, where the Light which it receives from the Sun may make it viſible.

16. That the Cauſe of the Appearance of the Beard, Tail, *or* Hair *of a Comet, is not in the place where it ſeems to us to be.*

16. As to the Rays which ſeem to compoſe the *Beard*, *Tail*, or *Hair* of a Comet; we ought not to think that they are cauſed by any particular matter which attends the Body of the Comet; becauſe we cannot ſee how the Poſition of this matter and the Poſition of the Sun can be in ſuch a manner adjuſted to each other; and becauſe of the prodigious Diſtance which this matter muſt extend itſelf to, (the Tail of a Comet taking up ſometimes a twelfth Part of the whole Compaſs of the Heavens;) both which make it very difficult to comprehend how ſuch matter ſhould always accompany the Body of a Comet.

17. That the Cauſe is not like that which cauſes Rays to be ſeen about a Candle.

17. Neither are we to think, that the Appearance of theſe Rays depends upon a Cauſe like that which makes us ſee Rays of Light about a Candle when we look upon it winking our Eyes; for theſe ceaſe entirely to appear, if we place an opake Body between our Eye and the Candle ſo as wholly to cover the Flame of it; whereas, if the Body of the Comet be wholly covered, we ſhall yet ſee the *Beard*, *Tail*, or *Hair*.

18. That the Beard, Tail *and* Hair *of a Comet are ſeen by Refraction.*

18. But our Opinion of this *Phænomenon* is, that it is cauſed by the Rays of Light reflected from the Body of the Comet, which being refracted in the intermediate Space, are ſo received by the Eye, as if they came from thoſe Places in the Heavens, where we ſee the *Hair*, *Beard*, or *Tail* of the Comet.

19. That this new Conjecture agrees with all the Phænomena of the Comets.

19. I could eaſily ſhew that this Conjecture agrees perfectly well with all the Phænomena of Comets; both with regard to the Inequality of their Appearances, Motions,

Motions, Duration and apparent Magnitudes; and with regard to the Diverſity of Rays with which they are attended: But becauſe all theſe Things are admirably well handled in the fore-mentioned Book; and becauſe ſuch an Undertaking would carry me too far out of my Way, I ſhall ſay no more; nor will I examine now whether it be true, that the Appearance of a Comet preſages any Calamity; for the Solution of this Difficulty, if it be one, may be deduced from what I ſhall ſay in the following Chapter concerning *the Influences of the Stars* [1].

1 Becauſe Comets are but ſeldom ſeen, and their Nature, Motion, Diſtance, Tails, *&c.* have been but of late Years accurately obſerved; I will here give you the principal Phænomena, by which all Hypotheſes ought to be tryed and examined.

Firſt then, the Comets which move forward according to the Order of the Signs, are all of them a little ſlower than uſual or retrograde, before they diſappear, if the Earth be betwixt them and the Sun; or elſe they are quicker than ordinary, if the Earth be on the oppoſite Side: And on the other Hand; thoſe which go contrary to the Order of the Signs, are quicker than uſual, if the Earth be betwixt them and the Sun; or ſlower than uſual, or elſe retrograde, if the Earth is on the oppoſite Side.

2. So long as they move very quick, they go almoſt in great Circles, but at the End of their Courſe they deviate from theſe Circles, and whenever the Earth moves one Way, they go the contrary.

3. They move in Ellipſes, whoſe Focus's are in the Center of the Sun, and if Rays be drawn from them to the Sun, they deſcribe Areas proportionable to the Times.

4. The Light of their Head increaſes as they go from the Earth towards the Sun, and decreaſes as they come from the Sun towards the Earth.

5. Their Tails appear largeſt and brighteſt immediately after they have paſſed by the Sun.

6. Their Tails are not directly oppoſite to the Sun, but always decline towards thoſe Parts where their Heads were before as they moved along in their Orbs.

7. And this Deviation is, *cæteris paribus*, leſs when their Heads approach near the Sun, and leſs towards the Head of the Comet, than towards the Extremity of the Tail.

8. The Tails are ſomewhat brighter, and terminated more diſtinctly on the convex than on the concave Side.

9. The Tails always appear broader towards the further End of them, than they do towards the Head of the Comet.

10. The Tails are tranſparent, and the ſmalleſt Stars may be ſeen thro' them.

Theſe are the Principal Phænomena of Comets; and it is eaſy to ſee how little they agree with the weak Conjectures of the Ancients, and the not very lucky Ones of the greateſt part of the modern Philoſophers; not to take Notice of theſe therefore, I ſhall briefly explain what ſeems to come neareſt to the Truth. There were ſome amongſt the Ancients (as *Pliny* tells us, *Book* II. *Chap.* 25.) 'who thought that theſe Stars were 'perpetual and came round in their 'Orbits, but could not be ſeen unleſs 'they were within reach of the Sun.' But *Seneca* is clearer, 'I cannot, '*ſays he,* (*Nat.* Quæſt. Book 7.) agree 'to the common Opinion; for I 'don't think that a Comet is a ſudden Fire, but one of the laſting 'Works of Nature, -- And why ſhould 'we wonder that Comets, which 'are Sights ſo ſeldom to be ſeen in 'the World, ſhould move by Laws 'as yet to us uncertain, and their 'beginnings and endings be hitherto 'unknown, when their Returns are 'at ſuch great Diſtances? — The 'Time will come, when the Diligence of future Ages will bring to 'Light what now lies hid. — The

'Time will come when Posterity 'will wonder that we were ignorant 'of such plain Things. — Some 'body will demonstrate at one Time 'or other, the Ways in which the 'Comets wander, and shew why 'they move so differently from the 'rest, and what sort of Things and 'how big they are.'

This, the famous Sir *Isaac Newton* has done in our Days, whose Opinion is, in short this: Comets are solid, compact, fixed and lasting Bodies in a Word, a sort of Planets which move with an oblique Determination all ways very freely, and continue in Motion a very great while, contrary to the Course of the Planets. Their Tail is a very thin Vapour, which the Head of the Comet sends forth when it is heated by the Sun.

Tab. XVIII. Fig. 3.

This being supposed, It is evident first, *That the Comets which move forward according to the Order of the Signs, ought to appear to move slower than usual, or to be retrograde, if the Earth be betwixt them and the Sun: And on the contrary, those which go contrary to the Order of the Signs*, &c. Because, as they do not wander about amongst the fixed Stars, but only amongst the Planets, so they, like the Planets, according as the Motion of the Earth conspires with or is contrary to theirs; must seem, sometimes to move quicker, sometimes slower, and sometimes to be retrograde.

2. *Comets, so long as they move quicker, must go almost in great Circles, but in the End of their Course, they ought to deviate*, &c. Because, at the End of their Course, when they go almost directly from the Earth, that Part of their apparent Motion which arises from the Parallax, bears a greater Proportion to the whole apparent Motion.

3. *Comets ought to move in Ellipses, whose Focus's are in the Center of the Sun*, &c. Because they do not wander with an uncertain Motion out of one fictitious Vortex into another, but as they belong to the Region of the Sun, they move round in an Orb with a constant and regular Motion.

4. *The Light of their Heads ought to increase as they go from the Earth towards the Sun*, &c. Because, as they move about amongst the Planets, their Approach to the Sun, must bear a very great Proportion to their whole Distance.

5. *Their Tails ought to appear largest and brightest, immediately after they have passed by the Sun.* Because their Heads being then most heated, send forth a great many Vapours.

6. *Their Tails ought not to be directly opposite to the Sun, but always to decline towards those Parts, where their Heads were before, as they moved along in their Orbs.* Because all Smoak or Vapours emitted from a Body in Motion ascends upwards obliquely, always receding from that Part where the smoaking Body goes.

7. *This Deviation ought to be less, near the Head of a Comet, and when the Comet moves near the Sun.* Because the Vapour ascends quicker near the Head of the Comet, than at the further end of the Tail; and so it does likewise, when the Comet is nearer the Sun, than when it is further off.

8. *The Tails ought to be somewhat brighter and more distinctly terminated on the convex than on the concave Side.* Because the Vapour on the convex Part, which goes first, being a little fresher and denser, reflects Light more copiously.

9. *The Tails ought to appear broader towards the further End than towards the Head of a Comet.* Because Vapour in free and open Space, is continually rarified and dilated.

10. *The Tails ought to be transparent, and the smallest Stars seen thro' them.* Because the Vapour they consist of is exceeding thin.

You may see more in the famous Sir *Isaac Newton's Principles, Book* III. *from Prop.* 39. *Lem.* 4. *to the End.*

CHAP.

CHAP. XXVII.

Of the Influences of the STARS, and of judicial Astrology.

IT is a common Enquiry, whether any Influences ought to be allowed to the Stars; the meaning of which Enquiry is, to be ſatisfied whether the Stars act in ſuch a manner, as to be the Cauſe of or at leaſt to contribute towards thoſe Effects which we ſee produced on the Earth.

1. What is meant by the Influences of the Stars.

2. That the Sun contributes to them, cannot be doubted; becauſe we may affirm that to be the ſole, at leaſt the principal Cauſe of all the Effects produced in it; for the Increaſing of Plants, the Flouriſhing of Corn, the Fruit coming to Perfection, ought all to be aſcribed to the Light or rather to the Heat of the Sun.

2. That there is no Doubt about the Influence of the Sun.

3. The Query is only about the other Stars therefore. And becauſe we feel the Light of them, that is an undoubted Proof, that they have a Power to ſhake the ſmall Fibres of the optick Nerves; and becauſe there is Matter in the Air, Water and Earth, which is finer and eaſier to be put in Motion than theſe Fibres, it muſt be granted, that they cannot but agitate and move it; and the Particles thereof, by moving afterwards more groſs matter, may produce ſenſible Effects; ſo that it is in ſome Senſe true, that the Stars may be the Cauſe of theſe Effects.

3. That the other Stars ought to be allowed ſome Influences alſo.

4. But becauſe we do not own any other Virtue to be in them by which they can act here below, but that of the Light which comes from them to us, we cannot allow them any further Power or Virtue in thoſe Effects produced upon the Earth, but in Proportion to their Light: And becauſe the Light of the Sun alone is infinitely greater than that of all the Stars put together, we ought to look upon that as the Cauſe of all theſe Effects. And if we do not always experience the ſame Conſtitution of Air, whenever the Sun ſends forth his Rays in the ſame Manner upon the Earth, we muſt not ſeek for the Cauſe hereof in the Stars, but look upon it as the Effect of the preſent Diſpoſition of the Air or the Earth.

4. That the Influences of the Stars are very inconſiderable compared with thoſe of the Sun.

5. Whence the Mistake of most Men about the Influences of the Stars proceeds.

5. I am persuaded that the ancient Philosophers, had no other Notions of the Influences of the Stars but such as these: But because the *Egyptians*, who were very good Astronomers thought fit to distinguish divers Days of the Solar Year, by the different fixed Stars, which rise immediately after Sun-set, and took Care to give Notice to the People of the Temperature of the Air which they observed in certain Seasons, and of what was proper for them to do in Agriculture, when certain Stars rise after Sun-set; they took that for the Cause, which was intended only for the Sign: And hence came the Notion of moist Stars whose Rising produced Rain, of others that caused Drought; of some that made Plants to grow, and of others which had a particular Dominion over certain Animals.

6. Why a great deal of Efficacy has been ascribed to the Planets.

6. The Experience we have of the Temperature of the Air being not always the same every Year, though the same fixed Stars never fail to rise when the Sun set, is enough to undeceive those who affirm that all Things here below depend upon the Stars: But because the Planets alter their Situation in the Heavens every Year; under this Pretence they have excused their Mistake, and taken Occasion from hence to ascribe to the Rising of the Planets, or to their different Situation in the Heavens, all those powerful Efficacies which they before ascribed to the fixed Stars.

7. The Rise of judicial Astrology.

7. And as the Vanity of Mens Minds is always increasing; after they had once suffered themselves to be prejudiced with this false Notion of the Virtue and Efficacy of the Planets; knowing that they could be certain of the Situation of the Planets for the Time to come, by Astronomical Calculation; they puffed themselves up with the Invention of an Art, which could foretel Things to come; as Rain, fair Weather, Wind, Thunder, Tempests, Plenty, Famine, War, and such like Things. This Art is what they call *Judicial Astrology*, which some boast themselves Masters of, and are got to such a pitch of Vanity as to promise to predict the most particular Actions and Fortunes of Persons.

8. That this Astrology hath no Foundation.

8. In order to avoid being deceived by such vain Promises as these; we ought to consider in the first Place, that this Astrology hath no Foundation; and that it cannot be proved by any Reason, that any such Powers are in the Stars, as Astrologers ascribe to them.

9. *Secondly*,

9. *Secondly*, It is certain, that they have not even Experience on their Side, which however they appeal to, and upon which they build their Art: For, as it would be ridiculous to affirm, that Experience ſhews us, that *Socrates*'s going out of Town, produced Thunder, becauſe it was obſerved to thunder once, at the Moment that this Philoſopher was got into the Road to go into the Country: So likewiſe is it ridiculous to affirm, that we have the Experience, that ſuch a particular Conſtitution of the Stars, produced, for Example, the Sickneſs of a Prince, becauſe it was once obſerved, that a Prince was ſick, when they were in ſuch a Diſpoſition. And indeed, ſo far are Aſtrologers from having many Times obſerved, what the Diſpoſition, which the Stars will be in to Morrow in the Heavens, is capable of producing; that ſtrictly ſpeaking, we may affirm, that they have not the leaſt Obſervation at all; becauſe it will take up ſeveral thouſand Years before ſuch a Conſtitution of the Stars as we have obſerved can happen twice. So that we may affirm, that ſuch a Conſtitution in the Heavens as will be to Morrow, has not yet been ſeen ſince the Creation of the World.

9. That Aſtrologers have not even Experience on their Side.

10. We may add to this; that if we allow Aſtrologers to have made ſome Obſervations of what has happened in former Ages, under certain Poſitions of the Stars; yet they would be of no uſe, but in the Countries where they were made; for it is certain, that whatever the Diſpoſition of the Heavens be, the ſame Clearneſs or the ſame Tempeſt does not reach over the whole Superficies of the Earth, but many Times, it rains very hard in one Country for a great Part of the Year, when in another Country not far off, it is very dry.

10. That the Experience of what comes to paſs in one Country, cannot make us certain of what is done in another.

11. Further; I cannot forbear taking Notice here, of the vain Credulity, or rather the fooliſh Error of moſt *Europeans*, about the Star called the *Dog*; who believe it to be of a hot Nature, and that it is the Cauſe of the Heat, that commonly happens about the Time that it riſes when the Sun riſes, and which is called the *Dog-Days*. For the People that live in the Southern Parts of the Earth, and over whoſe Zenith this Star paſſes, have much greater Reaſon to believe that it is of a cold Nature, becauſe at the ſame Time when this Star riſes with the Sun, which is the Seaſon wherein we often feel the greateſt Heat, they find the greateſt Cold, and are in the Depth of Winter.

11. The Miſtake of the Europæans *concerning the Dog Star.*

12. Perhaps,

12. That the Predictions of Astrologers may sometimes come to pass by Chance.

12. Perhaps it may here be said, that Astrologers do sometimes hit upon the Truth; which I do indeed allow: But this does not at all establish their Science; because there is no Person, be he ever so ignorant, but if he undertook to foretel Things to come, he would by chance hit upon some Things that come to pass, as well as upon some that did not, in the same manner as the greatest Astrologers in the World.

13. Of effects falsely ascrib'd to the Moon.

13. Not to insist any longer upon this Subject, which does not deserve to have any more said of it, and which is not worth being seriously treated by any Philosopher; I shall speak only one Word more about some false Opinions, which have been received by the Credulity of Men, and which Astrologers endeavour to confirm and turn to their own Advantage. Thus, it is generally thought that the Moon has a particular Virtue to corrode Stones; that the Bones of Animals are full of Marrow upon the Increase of the Moon, and have none in them but are full of Blood in its Wane; [1] and that Lobsters and Oysters and a great many other Fish, are fuller towards the new and full Moon, than at the *Quadratures*.

14. The Reason why some Stones seem to be eaten away.

14. As to the Eating away of Stones, the Moon is wrongfully accused hereof, because it never sends forth its Rays to any Places but where those of the Sun go also; so that it seems to me more reasonable to make the Sun the Cause of these Effects than the Moon: For it is highly credible, that in a Number of Years some Stones may be calcined by the Heat of the Sun, as they are by the Flame of a Candle in a few Hours. After which it is not at all surprising, that the Moisture of the Air should reduce Stones to Powder, as we see it does Lime.

1 *And that Lobsters and Oysters, &c.*) Pliny, Book II. Chap. 41. *And indeed the Bodies of Oysters, and all other Shell-Fish, increase and again diminish by the Power of the Moon.* And Chap. 99. *It is this (the Moon) which replenishes the Earth, filling Bodies as it approaches near, and emptying them as it goes farther off; and therefore Shell-Fish increase as that increases,* &c. You may find more of this in *Plutarch*'s *Entertaining Problems*, Book III. Prob. 10. *Why the Moon has more Power to corrupt Flesh than the Sun* and in *Macrobius*, Book VII. Chap. 16. But as to the real Power of the Moon; since it is evident, that it causes a greater *Flux* and *Reflux* in the Air than in the Sea, it must certainly produce some Alterations in the Temperature of the Heavens, and this may make some Alteration in the Bodies of Animals. But as to any other Effects commonly ascribed to the Moon and Planets, beyond what are owing to these Causes, they are mere Trifles.

15. It

15. It is alſo a great Miſtake to think that the Bones of Animals are full of Marrow at ſome particular Seaſons of the Moon, and empty at others; for I am ſure from above five and twenty Years Obſervation, that in all Quarters of the Moon, we may find ſome Bones full of Marrow, and others empty; ſo that this Difference depends upon ſome other Cauſe. And it is very probable, that the want of Marrow in ſome Animals proceeds from their not having ſufficient Nouriſhment, or from the Fatigues which ſuch Animals undergo. For I have taken Notice, that there was no Marrow at all to be found in the Bones of Sheep which were killed immediately after they were brought to *Paris* from Provinces a great Way off; whereas there is a great deal to be found in the Bones of thoſe who have reſted ſome Time in the Folds that are in the Suburbs of this City, where care was taken to feed them.

15. That the Bones of Animals are not full of Marrow at the Increaſe, and empty at the Decreaſe of the Moon; and whence this Difference proceeds.

16. The Notion, that Lobſters and Oyſters and other Fiſh, are fuller, or not ſo lean, in ſome Quarters of the Moon as in others, is alſo falſe, and contrary to all Experience: And this Error has crept in, like moſt others, by raſhly taking that for the Cauſe of an Effect, which really is not, but is only mere Chance and Hazard; and there is no Perſon who has taken ever ſo little Notice, but has a hundred Times in his Life, experienced the contrary to this and a great many ſuch like vulgar Opinions.

16. That the Notion of Lobſters, growing full and empty according to the Phaſes of the Moon, is falſe.

17. But if Fiſh be obſerved leaner at ſome particular Times than at others, it may proceed from hence; that they have not met with ſo much Nouriſhment, or that they have been put into too violent a Motion, and fretted either from the extraordinary Agitation of the Water, or by contending with each other: And this will appear highly probable to any one who knows, that the Fiſh taken in the Sea near *Calais*, where the Water is very rough, are commonly leaner than thoſe taken near *Bologn*, where the Sea is ſtiller: And indeed amongſt the ſame Kind of Fiſh, taken at the ſame Time, and in the ſame Place, thoſe which are catched in Nets let down into the Sea and drawn up again immediately, are plupmer and fuller than thoſe which are catched in Nets upon the Shallows, where they lie fretting themſelves for five or ſix Hours till the Tide goes back.

17. Why Fiſh ſhrink at ſome particular Times.

CHAP.

CHAP. XXVIII.

Of Gravity and Levity.

1. Whence the Names of Gravity and Levity arise.

IT has been always obſerved, that there are ſome Bodies which if they be not ſupported in the Air, will deſcend, and move towards the Center of the Earth; and that there are others, which, if at Liberty, will aſcend and move from the Center; and though the Principles of theſe Motions were not known, yet this did not hinder but that Names were given to them, the one being called *Gravity*, and the other *Levity*; But it is the Buſineſs of a Philoſopher to enquire into the Nature of theſe Things, and to explain what is meant by theſe Words.

2. Ariſtotle's Opinion about Gravity and Levity.

2. Some have aſſerted, amongſt whom *Ariſtotle* was one, that thoſe Bodies which we ſee deſcending, moved themſelves in ſuch a manner, by a particular Inclination which was in them to go towards the Center of the Earth, which was looked upon to be the Center of the Univerſe alſo. So likewiſe they aſſerted that the Bodies which we ſee aſcend, had a contrary Inclination by which they moved from the Center.

3. The Opinion of ſome other Philoſophers.

3. Others thought it ſuperfluous to admit two Sorts of Inclinations in Bodies, and therefore they contended, that it is more reaſonable to aſſert; that all Bodies have but one Inclination only, which makes them tend to the Center of the Univerſe; But ſome being carried with greater Force than others, the latter are obliged to remove further off, which makes them ſeem to be light. According to this Opinion, we ought to ſay, that Flame is heavy, and that when we ſee it aſcend, the Reaſon is, becauſe the Air in which it is, is heavier than it; in the ſame manner as we ſay the Cork riſes in the Water, becauſe Water is heavier than Cork.

4. A third Opinion.

4. To theſe two Opinions we may add a third, *viz.* that there is but one Inclination only in all the Bodies which ſurround us, and that is to aſcend; and that this Inclination is greater in the Fire, than in the Air, and that it is greater in the Air than in the Water, and that it is leaſt of all in the Earth: According to this Opinion; when a Stone deſcends in the Air or in the Water, we ought to ſay, that it proceeds from hence; that it was compelled by theſe two other Bodies, which having more Force than it to recede from the Center of the Earth, thruſt

thrust it that Way, and made it tend towards the Center.

5. As the two last Opinions are somewhat more simple than the first, because they suppose but one Inclination only in Bodies, they should seem to be the most probable: But this small Advantage is not enough for us to prefer them to the former; and to say the Truth, none of the Three are satisfactory: For if by the Word, Inclination, we understand any inward Sensation, or any particular Sort of Thought; I can't think that it can without Absurdity be ascribed to mere material Beings, such as Stones are. And if by this Word be meant only in general, a Cause, whatever it be, which produces these Motions by which Bodies are carried upwards and downwards, then it is only a mere Sophism; because it is saying nothing, but only purely giving the Name *Inclination* to something we know not what.

5. That these three Opinions are equally Faulty.

6. It is to be observed, that it is without any Reason that they who defend these Opinions assert, that the Center of the Earth is the Center of the World: For it is certain that we must know the Extremities before we can know the Center which is equally distant from them; but who can pretend to know the Extremities of the Universe; And if we mean to speak only of the visible World, what we have before established, is sufficient to convince us, that its Center is rather in the Sun than in the Earth.

6. That there is no Reason for affirming that heavy Things tend to the Center of the World.

7. In order to understand then more clearly and more distinctly, what the Gravity and Levity of Bodies consist in, and not to content ourselves with Words which we understand not the Meaning of; we must call to Mind that Rule which we formerly laid down, and which we said was one of the principal Laws of Nature, viz. *That the Parts of any whole which turns about its own Center, have a Tendency to recede from it, which Tendency is greater in those Parts which have more Motion than in those which have less.* Now since the Mass composed of Earth, Water and Air, turns abouts its Center; and it being certain that there is in this Mass a very great Number of Parts, which have more Motion than others; we may conclude that they do all of them really endeavour to recede from the Center about which they are turned, and therefore they may all in some Sense be said to be *light*; but because the Parts which have least Force to recede, are pushed with Violence towards the Center, by those Parts which have more

7. What Gravity and Levity consist in.

Force, this is the Reaſon why we find them to be heavy.

8. A notable Experiment to ſhew that a Body in moving round, tends to go off from the Center.

8. This is confirmed by a very remarkable Experiment which we are obliged to Mr. *Hugens* for; He took an earthen Veſſel which was white and round, about ſeven or eight Inches in Diameter, flat at the Bottom, and the Sides about three Inches high, and filled it with Water; then putting into it ſome beaten *Spaniſh Wax*, whoſe Weight made it ſink to the Bottom, and whoſe red Colour made it very viſible upon the white Bottom, he covered the veſſel with a Plate of very tranſparent Glaſs, and ſealed up the Edge ſo that nothing could get out; having done this, he faſtened the Veſſel on an Engine or Pivett, ſo that he could turn it about and ſtop it at Pleaſure. While the Veſſel was turning round in this manner, the Wax Powder which was at the Bottom of the Veſſel could not ſlip upon it ſo readily as the Water, but ſtuck a little to it, and therefore was more eaſily carried about; by this Means it acquired more Motion in turning round than the Water, and conſequently was forced to remove from the Center, and to ſpread itſelf, and get all round the Sides of the Veſſel; he then ſtopped the Motion of the Engine on a ſudden, and the Veſſel which was fixed to it conſequently ſtopped alſo; whereupon the *Spaniſh Wax* grating againſt the Bottom, and its Particles being rugged, did not move ſo quick as the Water whoſe Motion could not ſlacken ſo faſt, becauſe it can eaſily ſlide over the Body it moves upon. He ſhews us that at this Inſtant of Time, the Water reſembles the Fluid Matter which ſurrounds the Earth and the Powder of *Spaniſh Wax* reſembles Pieces of the Earth which we ſee deſcend in the Air; for the Powder was then forced to approach to the Center of its Motion, being driven thither by the Particles of the Water which endeavoured to recede with greater Force than the Powder which gathered into a little round Body in the Center like the Earth.

9. That Gravity is only leſs levity, and that the Deſcent of heavy things ought to be looked upon as natural.

9. By this Experiment we ſee clearly that Gravity is, properly ſpeaking, nothing elſe but leſs Levity; and though it follows from hence, that the Bodies which deſcend have no Diſpoſition in themſelves to deſcend; yet this Motion ought however to be called Natural, becauſe it is the Reſult of the eſtabliſhed Order of Nature.

10. Now

10. Now that there are ſome Parts of the Maſs compoſed of Earth, Water, and Air, which have more Motion than others, may be collected from hence; that the Earth is not turned about its Center in twenty-four Hours by its own Force, but is carried by the Current of a fluid Matter which ſurrounds it, and which penetrates all its Parts: For this Matter, by Reaſon of its Fluidity has more Motion than is requiſite to revolve along with the Earth in twenty-fours Hours; ſo that its Parts employ the reſt of their Force either to turn themſelves round ſwifter than the Earth the ſame Way, or elſe to move themſelves in an infinite Variety of different Ways: And becauſe the World is full, and it is with ſome Difficulty that they get out of the Place they are once in; therefore moſt of them muſt neceſſarily be determined to turn round in an innumerable Company of ſphærical Superficies concentrick to the Earth: And herein conſiſts the ſuperiour Force of this fluid Matter above other terreſtrial Parts, to recede from the Center of the Earth.

10. That the fluid Matter which encompaſſes the Earth has a greater Force to fly off from the Center than the Parts of the Earth.

11. When I am here ſpeaking of the fluid Matter which incompaſſes the Earth, I mean chiefly the Matter of the firſt and ſecond Element, which is in the Air, or in the Water; becauſe this Matter has the moſt Motion, and the Parts of Water or Air compared with this may be looked upon as terreſtrial Parts, they are ſo very much groſſer, and ſo little agitated; for though theſe Parts ſwim in that Matter, yet the contrary Impreſſions which they perpetually meet with from it, hinder them from acquiring any very rapid Motion, which might continue for a long Time.

11. That this Force belongs principally to the Matter of the firſt and ſecond Element.

12. Now in order to underſtand more clearly what the Action of the fluid Matter is, take a View of the following Figure, in which the Circle ABCD repreſents the Maſs compoſed of Earth, Water, and Air, whoſe Center is E; and the little Circle FGHI repreſents the Earth. Let us imagine in our Minds, that this Maſs is divided into a great many Pyramids whoſe Vertexes meet at the Center of the Earth, one of which is here repreſented by AEB; this being ſuppoſed, we are ſure in the firſt Place, that though the different Parts which compoſe each Pyramid, have a Tendency to recede from the Center E, yet they cannot recede all at once, becauſe there is no void Space round about this Maſs which they compoſe, and the Matter which is about them, hinders them

12. In what Caſe this force will produce no Effect.

Tab. XIV. Fig. 1.

them from moving out of their Places. We are certain likewiſe, that a ſingle Pyramid, ſuch as A E B, cannot retire whole from the Center, by ſpreading it ſelf and growing bigger at the Extremity A B, and ſo forcing the Matter on each Side to approach towards the Center, becauſe the Matter of the other Pyramids by which this is ſurrounded, have an equal Tendency and the ſame Force to recede from the Center likewiſe as the Pyramid A E B, at leaſt, if we ſuppoſe the terreſtrial Matter which is in each Pyramid, to be already as near the Center as it can be.

13. A particular Explication of the Gravity of a Body.

13. But if we ſuppoſe that there is a Terreſtrial Body, ſuch as L, in the Pyramid A E B, and none in the other Pyramids about it; it is eaſy to ſee that this Pyramid muſt have ſo much leſs Power to remove from the Center, than any of thoſe which ſurround it, as the Body L has leſs than the Quantity of Fluid had, whoſe Place it poſſeſſes; from whence it will follow, that the Matter of ſome of the Pyramids will recede from the Center, and [1] force the Body L to approach towards the Center, in the ſame Manner as they who affirm all Bodies to be heavy, ſay that the Water forces Cork to riſe up.

14. The

1. *Force the Body to approach towards the Center,* &c.] This was a very ingenious Hypotheſis, and ſo long as the World was thought to be full, a very probable one. But ſince it has been made appear by a great many very exact Obſervations of modern Philoſophers, that the World is not full; and that Gravity is the moſt ancient and moſt univerſal Property of Matter, and the principal of all in maintaining and keeping together the whole Univerſe; we muſt proceed in another Method, and find out another Theory of Gravity. To be ſhort, the celebrated Sir *Iſaac Newton* has purſued this Enquiry with that Succeſs, that the moſt ſimple Nature of Gravity, being ſuppoſed, he has eſtabliſhed the true Syſtem of the World beyond all Controverſy, and moſt clearly explained the moſt conſiderable Phænomena of all Nature. And his Opinion of the Nature and Properties of Gravity is this.

Every *ſingle* Particle of all Bodies whatever, *gravitates* to every *ſingle* Particle of all Bodies whatſoever; that is, they are impelled towards each other by Gravity, See *the Notes on Part* I. *Chap.* 11. *Art.* 15.

This gravitating Force is *Univerſal as to the Extent of it*; that is, all Bodies whatſoever, ſo far as we know, where ever they are placed, not only on the Earth, but alſo in the Heavens, whether in the Moon or Planets, in the Sun or any other Place, are endued with this Power.

This Force is alſo *univerſal as to the Kinds of Bodies*; that is, all Bodies, whatever their Figure, Form or Texture be, whether they be ſimple or compound, fluid or ſolid; whether they be great or ſmall; whether they be in Motion or at Reſt, are endued with this Power.

This Force is alſo *univerſal as to Time*; that is, all other Conditions being the ſame, it never increaſes or diminiſhes.

The

14. The Weight of a Body therefore is proportionable to the quantity of fluid Matter which causes it to descend; so that it seems the bigger any Body is, the more weighty it ought to be.

14. That the larger Bodies are, the more heavy are they.

15. How-

The Quantity of this Gravity at equal Distances, is always exactly in Proportion to the Quantity of Matter in the gravitating Bodies. For Instance, *if a cubit Foot of Gold has a Thousand Pound Weight* upon the Superficies of the Earth, *two cubit Feet* will have two *Thousand Pound Weight* upon the same Superficies; and if the Earth contained but half the Quantity of Matter that it does now, the same cubick Foot of Gold which has now *a thousand Pound Weight* upon the Superficies of the Earth, would have but *Five Hundred only*.

This Gravity in given Bodies is greater or less according to the Distance of those Bodies from each other; for Example, a Stone which near the Superficies of the Earth, is very heavy, if it were carried up as high as the Moon would be very light.

Lastly, The Proportion of the Increase or Decrease of this Gravity in Bodies approaching to or receding from each other is such that its Force is reciprocally in a duplicate Proportion or as the Squares of their Distances. For Example, a Body which at the Distance of ten Diameters of the Earth, weighs a hundred Pounds; would, if its Distance were but half so far, weigh four Times as much; and if but a third Part so far, nine Times as much. So likewise, the Force which upon the Superficies of the Earth, could support a Hundred Pound Weight; if it were twice as far off the Center, could support four times the Weight, if three Times as far off, it could support nine Times the Weight.

Having laid this down for the Nature of Gravity, it follows:

First, That Gravity or the Weight of Bodies is not any accidental Effect of Motion or of any very subtle Matter, but an original and general Law of all Matter impressed upon it by God, and maintained in it perpetually by some efficient Power, which penetrates the solid Substance of it; for Gravity never is in Proportion to the Superficies of Bodies or of any Corpuscles, but always to the solid Quantity of them. Wherefore we ought no more to enquire how Bodies gravitate, than how Bodies began first to be moved.

Secondly, Hence it follows, that there is really a *Vacuum* in Nature, and that it is much the greatest Part. For since Gravity is an universal Affection of Matter, if we suppose the World to be full, it would follow, that all Bodies would be equally heavy: which is very absurd.

Thirdly, This being laid down for the Nature of Gravity; it will follow, that the Planets, if they have once impressed upon them by God, the most simple projectile Motion in straight Lines, will revolve about the Sun, as we see they really do, in Circles or Ellipses, without the Help of Vortexes. See *the Notes on Chap.* XXV. *Art.* 22. *of this Part.*

Fourthly, Hence it follows, that if any very great Collection of fluid Matter be gathered together upon the Superficies of the Earth, it must flow backward and forward according to the various Motions of the Sun and Moon, because of its gravitating towards them, in proportion to their Magnitudes and Distances. See *the Notes on the following Chap.*

Lastly, So easy and agreeable to the nature of Things, is this Notion of Gravity, that *Kepler*, though he could not explain the Manner of the cælestial Motions by it, yet he contended that it was true.

Gravity, says he, *is a corporeal Affection, which is mutual betwixt Bodies of the same Nature*, &c.

If the Earth was not round, heavy Bodies would not descend from all Parts directly toward the Center of the Earth; but from different Sides would descend towards different Points.

If two Stones were placed near each other, in any Place of the World, out of the Reach of the Action of any third Body of the same Nature; these Stones in the same Manner as two Load-Stones, would meet in an intermediate Place, each approaching to the other by

such

15. Why Bodies of unequal Bigness weigh alike.

15. However this is not always true, nor is it ever ſo but when all Circumſtances are alike; for it is to be obſerved, that all terreſtrial Bodies have Pores, which the Matter of the firſt and ſecond Element can very eaſily enter into; they muſt neceſſarily always contain in them a certain Quantity of that Matter; which having juſt as much Force, as an equal Quantity of the ſame Matter, which is in the Pores of an equal Portion of Air that muſt aſcend into the Place of the terreſtrial Body, it is only the Difference betwixt the two Quantities of ſubtle Matter that ought to be conſidered: Further, there is always a certain Quantity of terreſtrial Matter in every Portion of Air likewiſe, which ought to be deducted out of that which compoſes the heavy Body with which it is compared: So that the whole Weight of a Body conſiſts in this, that the Remainder of the ſubtle Matter, which is in the Portion of Air that ſucceeds in the room of the heavy Body, has more Force to go off from the Center of the Earth than the Remainder of the terreſtrial Matter, which compoſes the heavy Body. And as Things may be diverſified a great many Ways, from hence ariſes the unequal Weight of different Bodies of the ſame Bigneſs; and this is alſo the Reaſon, that ſome which are very large, do notwithſtanding weigh but a little.

16. Why the Celerity of heavy Bodies increaſes as they fall.

16. As to the Velocity with which heavy Bodies fall towards the Earth, and the Proportion which Bodies of different Weight obſerve in falling, there are many Particulars worth our Notice; and *Firſt*, it may be demanded; Whence it is that their Celerity increaſes in Proportion to their Deſcent in the Air? To which it is eaſy to anſwer; that when a Body begins to deſcend, its Velocity cannot be very great, becauſe the ſubtle Matter which is about it getting into its Place, and which is all that it is impelled by, cannot force it downwards with ſo great a Celerity, as it has itſelf to recede from the

ſuch an Interval as is proportional to the other's Bulk.

If the Moon and the Earth were not kept each in their Orbits, by an animal Force, or ſomething equivalent to it; the Earth would aſcend towards the Moon a fifty-fourth Part of the Diſtance between them, and the Moon would deſcend towards the Earth fifty-three Parts of the Diſtance or thereabouts; and there they would be united together. This would be ſo upon Suppoſition, that the Matter of them both is of the ſame Denſity. See *Kepler*'s Introduction to his Book concerning the Motions of *Mars*.

But as to the *efficient Cauſe* of this Gravity, as we have called it, See above *Chap.* XI. *Art.* 15. *of the firſt Part.*

Center

Center of the Earth. But when it is once put in Motion and begins to deſcend, the ſubtle Matter which is underneath it, and which tends with its whole Force to aſcend as high as it can, puſhes it downwards continually, and ſo perpetually adds new Degrees of Celerity to thoſe which it had before. And this is the Reaſon why the [1] Celerity encreaſes every Moment, and that its Fall is the more or leſs violent, according to the greater or leſſer Height from whence it begins to deſcend.

17. It

1 *The Celerity increaſes every Moment*, &c.] The Motion of falling Bodies is increaſed in the proportion of odd Numbers, 1, 3, 5, 7, 9, &c. So that the Spaces run through, are as the Squares of the Times, that is, if a heavy Body deſcend a Foot in one Moment, it will deſcend four Foot in two Moments, nine Foot in three Moments. *&c.*

But becauſe this is one of the Principal Phænomena of Nature, I ſhall add a fuller Diſſertation upon this Matter.

The famous Sir *Iſaac Newton* has ſhewn, that the Gravity of Bodies which are above the Superficies of the Earth, is reciprocally as the Squares of their Diſtances from its Center; But the Theorems concerning the Deſcent of heavy Bodies, demonſtrated by *Gallilæus*, *Hugens*, and others, are built upon this Foundation, that the Action of Gravity is the ſame at all Diſtances: The Conſequences of which Hypotheſis, are found to be very nearly agreeable to Experience, becauſe the Spaces to which Bodies can be carried above the Superficies, are ſo very ſmall compared with the length of the Earth's Semi-diameter; that the Difference of the Diſtances from its Center, may be looked upon as nothing. Suppoſing therefore the Action of Gravity to be equable, and that there is no Reſiſtance in the Medium through which Bodies fall; the following Theorems may be thus demonſtrated.

Prop. I.

The Velocities acquired by a *heavy Body*, which was at reſt till it began to fall, at the Concluſion of any Times computed from the Beginning of their Fall, bear the ſame Proportion to each other as theſe Times.

For it is evident; that in a Motion performed in the ſame ſtraight Line, and accelerated by equal and ſucceſſive Impulſes, the Velocities acquired, muſt be as the Number of Impulſes. If therefore we imagine the Time of the Deſcent to be divided into infinitely ſmall and equal Moments or Points of Time, and that the Force by which the *heavy Body* is urged downward, adds in every one of theſe Moments a new Impulſe to it, always equal to the foregoing one; that is, acts upon it continually in the ſame Way and Manner; it is manifeſt that the *heavy Body* may be apprehended to have received as many Impulſes while it was falling, as there are Moments of Time computed from the Beginning of its Deſcent: The Velocities acquired therefore, are as the Number of Moments computed, that is, as the Times taken up in falling. Q. E. D.

Coroll.

In the right angled Triangle ABC, if AB, AD repreſent the Times of Deſcent; and if BC repreſents the Velocity acquired at the End of the Time AB; then DE parallel to BC will repreſent the Velocity at the End of the Time AD. Tab. XXI. Fig. 1.

Prop. II.

The Spaces run through by a *heavy Body* which was at reſt before it began to fall, in any Times computed from the Beginning of the Fall, are in a duplicate Proportion both of thoſe

Times,

17. That the Velocity may be so great, as not to be increased.

17. It is true, and it is the Second Particular here to be considered, that a Body may arrive to such a Degree of

Times, and of the Velocities acquired at the End of those Times.

For it is evident, that the Spaces which a *heavy Body* passes through in falling, in any Times whatsoever, are to one another, as the Sums of the Velocities with which the heavy Body is carried in every one of the Moments of those Times. Now the preceding Corollary being granted, every one of the Lines that are parallel to DE in the Triangle ADE, do each of them represent every one of the Velocities with which the heavy Body is carried in the Correspondent Moments of the Time represented by AD (*by the preceding Coroll.*) Therefore the Sum of these Lines or the Triangle ADE will represent the Sum of all the Velocities with which the *heavy Body* is carried in the Time AD. For the same Reason the Triangle ABC will represent the Sum of the Velocities with which the *heavy Body* is carried in the Time AB. The Spaces therefore run through in the Times AD, AB are to each other as the Triangles ADE, ABC. But these Triangles are to one another in a duplicate Proportion as well of AD to AB, as of DE to BC, that is, as well of the Times of their Descent as of their final Velocities. The Spaces therefore run through, are to one another in the same Proportion. Q. E. D.

Coroll.

If the Times, computed from the Beginning of the Fall, be to one another as Numbers increasing in the Rank 1, 2, 3, 4, &c. the Spaces run through in these Times, will be as the Squares of these Numbers; *viz.* as the Numbers 1, 4, 9, 16, &c. and the Spaces run through in equal contiguous Times, will be as the odd Numbers 1, 3, 5, 7, &c.

Prop. III.

The Space run through by a *heavy Body* which was at rest before it began to fall, in any Time whatsoever, is half the Space which it would run through in the same Time with an equable Motion, with the Velocity acquired in the last Moment of its Fall.

Let AB represent the Time of the Descent; BC the Velocity acquired at the End of it, and let the Triangle ABC be completed into the Parallelogram BF: It is manifest, that the Space passed through in the Time AB, with the equable Velocity BC, is rightly represented by this Parallelogram. But the Triangle ABC is half this Parallelogram. Therefore &c. Q. E. D.

Tab. XXI. Fig. 1.

N. B. The three foregoing Theorems are true also if applied to *heavy Bodies* descending upon any inclined Planes; because they are urged along those Planes by a Force which is given and equable, and which is to the Force of Gravity, as the Height of the Plane to the Length of it. *See the Notes on Part* I. *Chap.* 17. *Art.* 9. *Prop.* 2.

Prop. IV.

The Velocity ultimately acquired in falling along any inclined Plane AC, is equal to the Velocity acquired in falling the Altitude of it AB; and therefore the Velocities ultimately acquired in falling along any inclined Planes AC, AD whose Altitude is the same, are equal: And the Times of their Descent along the same Planes, are as the Lengths of those Planes.

Tab. XXI. Fig. 2.

From what has been already said, it is evident; that in Motions equably accelerated, the Velocities generated in a given Time, and consequently the Spaces run through, are to each other as the Forces by which the Velocity is generated.

First then, let the perpendicular BP be let fall from B to AC; and the *heavy Body* in descending along AC, will arrive at P, in the same Time that it would arrive at B in falling from A; (for AB is to AP, as AC to AB; that is, as the Force with which the *heavy Body* is urged along AB, to the Force with which it is urged along the Plane AC;) wherefore the

of Celerity, as cannot be further increaſed; either becauſe the Air is uncapable of opening any freer Paſſage for it; or

the Velocity in B is alſo to the Velocity in P, as AB, to AP; but the Velocity in P, is to the Velocity in C, in a ſub-duplicate Ratio (*by Prop.* 2.) of AP to AC, that is, as AP to AB. The Velocity in B therefore, is to the Velocity in C, in a Ratio compounded of AB to AP, and AP to AB; but this is a Ratio of Equality. Therefore &c. *Secondly*, Becauſe the Time of the Deſcent from A to P, is to the Time of Deſcent from A to C, in a ſub-duplicate Ratio (*by Prop.* 2.) of AP to AC alſo; that is, as AP to AB, or as AB to AC; and becauſe a *heavy Body* in falling from A will arrive at B in the ſame Time as at P; therefore the Time of Deſcent along AB, is to the Time of Deſcent along AC, as AB to AC. And for the ſame Reaſon, the Time along AD, as AB to AD. Therefore &c. Q. E. D.

Prop. V.

If the Diameter AB of any Circle be erected perpendicular to the Horizon, the Times of Deſcent along any Chords, ſuch as BC drawn from the Extremity of it, are equal. And the Velocities acquired in the Point B are to each other as thoſe Chords.

Tab. XXI. Fig. 3.

For if CD be let fall perpendicular from C to AB; *firſt*, the Time of Deſcent from A to B, is to the Time of Deſcent from D to B, as AB to CB (*by Prop.* 2.) And the Time from D to B, is to the Time from C to B; as DB to CB (*by Prop.* 4.) Therefore the Time from A to B, is to the Time from C to B in the Ratio compounded of AB to BC and DB to BC, or as AB x BD, to BCq. But theſe are equal, and conſequently the Times of Deſcent are equal. Wherefore, ſince the Times of Deſcent along any Chords are all equal to the Time of Deſcent through the Diameter; they are alſo equal to each other. *Secondly*, The Velocity acquired in falling from D to B, and from C to B, is the ſame; (*by Prop.* 4.) Now this Latter, is to the Velocity acquired in falling from A to B, as CB to AB (*by Prop.* 2.) Therefore &c. Q. E. D.

Coroll.

Hence we ſee the Reaſon, why the Times of the Vibrations of a Pendulum deſcribing very ſmall Arches of a Circle, are very nearly equal; for thoſe Arches differ very little from their Chords, either in Length or Poſition.

Prop. VI.

If a *heavy Body* deſcends from any Altitude through never ſo many contiguous Planes of any Sort, and any Inclination whatſoever AB, BC, CD; it will acquire the ſame Velocity at the laſt, as it would acquire in falling perpendicularly from the ſame Height.

Tab. XXI. Fig. 4.

Let AF, DG, be drawn parallel to the Horizon; let CB, DC be produced till they meet AF in the Points E and F, and let the perpendicular FG be let fall.

The *heavy Body* in falling from A to B, will acquire the ſame Velocity, as if it had come to B along EB, (*by Prop.* 4.) Wherefore, ſince the turning out of its Courſe at B is ſuppoſed no Way to hinder its Motion, it will have the ſame Velocity in C, as if it had deſcended along EC; that is, as if it had deſcended along CF, (*by Prop.* 4.) Therefore it will have the ſame Velocity in D as if it had deſcended along FD: And this is equal to that which it would have had in falling perpendicularly along FG, (*by Prop.* 4.) Therefore &c. Q. E. D.

Coroll.

A *heavy Body* deſcending in any Curve, will acquire the ſame Velocity as it would acquire in falling from the ſame perpendicular Height; for a Curve may be looked upon as compoſed of an infinite Number of ſtraight Lines.

or because it having acquired as much Motion downwards as the subtle Matter itself, which causes it to descend, has

Prop. VII.

If the Inclination of any Number of contiguous Planes whatsoever, AB, BC, CD; a b, b c, c d, be in the same; and the Ratio of their Lengths be the same; the Times in which they will be run through by a *heavy Body*, will be in a sub-duplicate Ratio of those Lengths taken together.

Tab. XXI. Fig. 4, 5.

Let A F, a f, be drawn parallel to the Horizon; and let BC, CD; b c, c d, be produced till they meet A F, a f, in E and F, e and f. It is evident, by the Hypothesis, that BE has the same Ratio to b e, and CE to c e, and DF to d f; as AB has to a b or BC to b c, or CD to c d; and also as AB + BC + CD has to a b + b c + c d. Now because of the equal Angles BAE, b a e, the Times of the Descents along AB, a b, will be in a sub-duplicate Ratio of AB to a b; (*by Prop.* 2.) and the Velocities in the Points B and b will be in the same as would have been acquired in falling along EB e b (*by Prop.* 4.) If therefore the Motion be continued, the Spaces B C b c, will be run through in the same Times as if the *heavy Body* had begun to fall from the Points E e. But the Times of the Descents as well thro' E B, e b, as through E C, e c, are in a sub-duplicate Ratio of those Lines, that is, in a sub-duplicate Ratio of AB to a b. Therefore (*by Division*) the Times along BC, b c, after having fallen along A B, a b, are in the same Ratio. And therefore (*by Composition*) the times along A B + B C + C D, a b + b c + c d, are in the same Ratio also. In the same manner may it be demonstrated that the Times of passing through A B + B C + C D, a b + b c + c d, are in the same Ratio of AB to a b, or of AB + BC + CD, to a b + b c + c d, and so on for ever, let the Number of Planes be never so many. Therefore &c. Q. E. D.

Coroll. 1.

The Times in which a *heavy Body* runs through similar Parts of Curves whose Position is the same, are in a sub-duplicate Ratio of those Parts. For those Parts of Curves may be looked upon as composed of an infinite Number of straight Lines whose Ratio is given, and their Inclination to each other Similar.

Coroll. 2.

The Times in which Pendulums describing similar Arches of Circles vibrate, are in a sub-duplicate Ratio of the Lengths of the Threads; for these Threads or Radius's of Circles are in the same Ratio as their similar Arches. And the same holds true though the Arches be not similar, provided they be very small, (by Coroll. Prop. V.)

The following Propositions may also be very properly added in this Place.

Of the Motion of Projectiles.

The same Law of Gravity being supposed as before, and that there is no Resistance from the Medium, and that heavy Bodies descend perpendicularly to a given horizontal Plane; (which Hypothesis, because of the small Spaces through which Bodies are projected, compared with the Earth's Circumference, differs very insensibly from the Truth) the Affections of the Motion of Projectiles may easily be demonstrated.

Prop. VIII.

If a Body goes along with a compound Motion, consisting of an equable Motion in a straight Line given in Position, and of the Motion arising from the Force of Gravity: It will describe a parabolick Curve, which the straight Line given in Position, will touch in the Point where the Body begins to move, and all the Diameters of this Curve will be perpendicular to the Horizon.

Let the Body be moved from the Point P, with an equable Motion according to the Direction of the Line PL given in Position; and at the same Time let it be drawn downwards by its own Gravity, according

has upwards; there remains nothing that can give it any new Degrees of Motion which might increaſe its Celerity.

18. *Laſtly*,

cording to the Direction of PG, perpendicular to the Horizon PH. Now ſince neither of theſe Motions hinder the other ſo, but that the Body may go on according to the Direction of the Line PL in the ſame manner, as if the Force of Gravity did not act at all; and that it may likewiſe deſcend according to the Direction of the Line PG in the ſame manner as if it had not been impelled by the projectile Motion: If the Body moves through the Spaces PL, Pl with an equable Motion, in the ſame Times as they will fall through the Spaces PG, Pg; it is manifeſt, that if GV gv be drawn parallel to PL, and LV, lv, parallel to PG, till they meet each other in the Points V, v, the Body will be found at the End of thoſe Times in the Points V, v: Now becauſe in the Motion along the Line PL is equable, PL, Pl, will be to each other as the Times in which they are paſſed through; but PG will be to Pg as the Squares of thoſe Times, (*by Prop.* 2.) PG therefore or LV, is to Pg or lv, as PLq: to Plq: All the Points Vv, therefore are in a parabolick Curve, which PL touches in the Point P, and all the Diameters of which are parallel to PG, that is, perpendicular to the Horizon, Q. E. D.

Tab. XXIII. Fig. 1.

When I mention hereafter the Parameter ſingly, you are to underſtand that Parameter which belongs to that Point in the Curve deſcribed from whence the Projection is made.

Prop. IX.

The Velocity with which the Body is projected along the Line PL, is equal to that which it would acquire in falling thro' a fourth Part of the Parameter.

Tab. XXIII. Fig. 1.

A Body with an equable Motion paſſes through the Space Pl, in the ſame Time that it falls through the Space lv. Now if Pl be taken equal to half the Parameter, lv will be equal to half Pl. Now the Velocity acquired in falling through lv is ſuch that double the Space lv, that is, the Space Pl would be run through in the Time of its Fall (*by Prop.* 3.) But the Body by the projectile Motion paſſes through the ſame Space Pl in the ſame Time. So that the Velocity of the one is equal to the Velocity of the other, Q. E. D.

Coroll. 1.

If the Velocity of the projectile Motion be the ſame, the Parameter will be the ſame, whatever the Direction of the Projection be.

Corol. 2.

The Velocity of a projected Body in any Point of the Curve which it deſcribes, is the ſame as it would acquire in falling through a fourth Part of the Parameter belonging to that Point; and therefore the Velocities of it in different Points are in a ſub-duplicate Ratio of the Parameters belonging to thoſe Points, (*by Prop.* 2.) For the projected Body may be conſidered in any Point of the Curve deſcribed as if it began to be moved firſt in that Point according to the Tangent of it, and afterwards deſcribed the reſt of the Curve.

Coroll. 3.

The Velocity of a projected Body is leaſt therefore when it is in the Axis of the Curve; and is the ſame at equal Diſtances from the Axis on each Side; and the greater the more remote it is from the Axis: And the Velocities of it in different Points, are to each other as the Secants of the Angles which the Tangents to thoſe Points when produced, make with the horizontal Line. For let the ſtraight Line PL touch the Curve in the Point P; and meet any Diameter VH produced in L, and let PO be an Ordinate from the Point P to the ſame Diameter, which

Tab. XXIII. Fig. 2.

18. That the Celerity of the Fall of unequally heavy Bodies, is not proportionable to their Weight.

18. *Lastly*, In order to determine the Proportion observed by Bodies of unequal Weight in their falling, the follow-

will therefore make the same Angles with the horizontal Line PH, as the Tangent of the Curve in the Point V does. Now if PH be the Radius, P L, P O will be the Secants of the forementioned Angles: And it is easy to shew from the conick Sections, that these Secants are to each other in a sub-duplicate Ratio of the Parameters belonging to the Points P and V, that is, (*by the preceding Coroll.*) as the Velocities of the projected Body in the Points P, V.

Coroll. 4.

Let the projected Body begin to move from the Point A, according to any Direction AT: Let the horizontal Line AH be drawn, and AP erected perpendicularly to it, and equal to a fourth Part of the Parameter of any Curve to be described with a given Force. On the Diameter AP let the Semicircle ATP be described, cutting the Direction of the projected Body in T. From whence let TF be let fall perpendicular to PA. Now since the projected Body can run through a Space double to PA with the Velocity acquired in falling through PA, and in the same Time (*by Prop.* 3.) and since this Velocity is equal to that with which the projected Body goes out from the Point A: (*by Prop.* 9.) If AP represents the Time of falling from P to A, the projected Body will be carried in the Line of its Direction AT through a Space double to AT, in the Time represented by the Line AT, and through a Space four Times the Length of AT, in twice the Time of AT. Let that Space be AE, and from E let the perpendicular EH be let fall to the horizontal Line. Further, in the Time represented by AT the projected Body will fall through the Space FA (*by Prop.* 2.) and in the Time represented by double AT, it will fall through four Times the Space FA or through the Space EH: That is, in the same Time that the Body by its projectile Motion passes through the Space AE, it will fall through the Space EH, and so meet the Horizon; but AH is its horizontal Space, and AF the Altitude of the Parabola described. Whence the following Consectaries flow also.

Tab. XXIII. Fig. 3.

Coroll. 5.

The horizontal Spaces described by a projected Body with a given Force, are to each other as the Sines of double the Angles which are made by their Directions and the horizontal Line; And therefore its greatest horizontal Space, is, when that Angle is half a right Angle; and it is equal to half the Parameter of the Curve described; and these Spaces are equal, when the Directions of the projected Body differ from a right Angle by equal Angles on each Side; for these Spaces are as the Lines FT; and, if CT be Radius, FT is the Sine of the Angle FCT which is double EAH, whence the rest are manifest.

Coroll. 6.

The Altitudes of the Curves described, are to each other, as the versed Sines of the aforesaid Angles, for they are equal to the Lines FA.

Coroll. 7.

The Times which a projected Body takes up in describing those Parts of the Curves, which are cut off by the horizontal Line, drawn through the Point where the projection is, are to each other as the Sines of the Angles which the Directions make with the horizontal Line; for they are to each other as the Lines AT, which if PA be Radius, are as the Sines of the Angles APT, or EAH.

Prop. X.

The horizontal Distance PH, of any Point V in the Curve which the projected Body describes from the Point P where the Projection is made; its perpendicular Distance from the Horizon VH; and the Angle LPH which

Tab. XXIII. Fig. 2.

following Rule is diligently to be considered; *viz.* that a Body which moves very quick, may increase the Celerity

which the Direction of the projected Body makes with the horizontal Line, being given; to find the Parameter and the Velocity of the projectile Motion.

PH and the Angle LPH being given, PL and LH are given; wherefore because VH is given, VL is also given; Therefore $\frac{PLq}{LV}$ the Parameter is also given. And since the Space which a Body falls through in a given Time, is given; viz. $16\frac{1}{2}$ *London* Feet, in a second of Time; it is easy to collect from the *second* Prop. what the Time of the Descent through the given Line LV is, that is, the Time which the given Line PL is run through by the projectile Motion, Q. E. J.

Prop. XI.

Let B be a Mark or any given Point, let BD be its perpendicular Distance from the horizontal Plane, and let GD be the horizontal Distance of another given Point G in the same Plane. Let GB be joined; and from the Point G, let GP be erected perpendicular to DG; and let the Angle BGP be bisected, by the straight Line GN; Now if the Mark B be hit by a Projection made according to any Direction GK; I say, that the same Mark B will be hit by a Projection made with the same Force, according to another Direction GL, which makes the Angle LGN with the bisecting Line, equal to the Angle NGK. Let the forementioned Directions meet DB produced, in the Points K and L. Because the Velocity of the projected Body, according to the Lines GK, GL, is supposed to be the same, the Times which it takes up in passing through them, are in the same Ratio as the Lines themselves; but the Spaces which it falls through from the Points K and L, in those Times, are to each other, as the Squares of the Times; (*by Prop.* 2.) they are therefore as GKq, to GLq. Now

Tab. XXIII. Fig. 4, 5.

because of the similar Triangles GKB, LGB; BK is to BG as GK to GL; and BK to BG as BG to BL. Therefore as GKq; is to GLq. so is BK to BL. Wherefore since BK (*by the Hypoth. and Prop.* 8.) is the Descent of the projected Body from the Point K, in the Time GK LB will be its Descent from the Point L in the Time GL. Therefore (*by Prop.* 8.) the same Mark B will be hit by the Direction GL also, Q. E. D.

Coroll. I.

If LK be bisected in F, DF will be equal to half the Parameter of the Curves described. For the Rectangle of the Parameter and LB is equal to GLq; and the Rectangle of the same Parameter and KB, is equal to GKq. Therefore the Rectangle of the same Parameter and LK is equal to GLq; — GKq: or DLq — DKq, or to the Rectangle of $DL \mp DK$, that is, LK into $DL \pm DK$. The Parameter therefore is equal to $DL \pm DK$, the half of which is DF.

Coroll. II.

The nearer the Directions GK, GL, are to the Line which bisects the Angle BGP, the less is the Force required to hit the Mark B; so that there are no more than two Directions, along which the same Mark may be hit with the same Force. For let the bisecting Line meet BD produced in N. Now since the Directions GK, GL, are distant from GN by equal Angles, (*by Prop.* 3. *Book* VI. *of Euclid*) it is evident that the Point F must fall higher than the Point N, or DF must be greater than DN; and if GL and GK approach to GN, the Point F ought to come to the Point N, that is, the Parameter will be lessened (*by the preced. Cor.* 2.) and consequently the Force of the projectile Motion (*by Prop.* 9.)

Coroll.

lerity of another Body which moves flower, by impelling it forward when it overtakes it; But if we fuppofe it to have

Coroll. III.

If the Direction of the Force with which the given Mark B is hit, be the Line GN itfelf, which bifects the Angle BGP, then that Force is the leaft, and the Direction the only one, in which the Mark B can be hit with that Force: And the contrary. For when GK, GL, coincide with GN, the Point F will coincide with N, and DN will be half the Parameter: Then the reft will follow from Prop. XI, and the preceding Corollaries.

Coroll. IV.

Hence we fee the Reafon of the Mechanical Practice of directing a Cannon fo as to hit the Mark with the leaft Force. For having fixed a plain Looking Glafs perpendicular to the Bore of the Cannon; let the Cannon be inclined, till the Eye, looking along a Thread hanging freely with a Lead at the End of it, can fee the Mark reflected by that part of the Looking-Glafs over which the Lead hangs; Then, it is evident, *from the Nature of Reflexion and the preced. Corol.* that you have the Direction required.

Coroll. V.

The higheft Points which can be hit with a given Force, at any horizontal Diftances, are all of them in the Curve of a Parabola, whofe Focus is the Point from whence the Projections are made; whofe Axis is perpendicular to the Horizon; and the Parameter to the Axis, the fame as that of all Curves defcribed with a given Force.

Tab. XXIV. Fig. 1. For let GPH be a Parabola, G the Focus, GP the Axis perpendicular to the Horizon; the Parameter to the Axis the fame as that of Curves defcribed with a given Force. Let any horizontal Diftance GD be taken, and from the Point D, let the Perpendicular DB be erected, meeting the Curve in B; I fay, the Point B is the higheft that can be hit with a given Force, at the Diftance GD; or the given Force is the leaft that can hit that Point. For if GB be drawn, GB $\pm$ BD will be equal to half the Parameter of the Curve defcribed by the leaft Force that B can be hit by. For in order to have that Force hit the Point B, the Direction muft bifect the Angle BGP; (*by Cor.* 3.) then by reafon of that Angle's being fo bifected, and DB, GP, being parallel, the Triangle GBN will be Ifofceles; and GB $\pm$ BD equal to DN, that is to half the Parameter; as is evident from that Corollary. Tab. XXIII. Fig. 4, and 5. Now in the Parabola GPH, let BO be an Ordinate to the Axis, and let the Tangent BT be drawn, meeting the Axis produced in T; Tab. XXIV. Fig. 1. then (*becaufe from the Nature of the Parabola,* PO and PT, GB and GT, GO and DB are equal) GB $\pm$ DB is equal to double GP, that is, (*by Conftruct.*) equal to half a Parameter of the Curve defcribed by a given Force. Therefore the given Force is the leaft by which the Point B in the Curve of the Parabola GBH can be hit: Whence the Thing propofed is manifeft.

Coroll. VI.

Tab. XXIII. Fig. 4, and 5. If DF be given and equal to half the Parameter of the Curves paffing thro' the Point B, and from the Point F be taken equal Lines FL, FK, fo as that GL, GK being drawn they may make equal Angles with the Line GN, which bifects the Angle BGP; GL and GK will be the Directions of Force with which thofe Curves paffing through B will be defcribed.

Prop.

have neither greater nor less Celerity, than that which it meets with, it can only go along with, or follow in its Fall,

Prop. XII.

Tab: XXIV. Fig. 2. and. 3.

G D the horizontal Distance of the Point B, D B the Altitude, and D F half the Parameter, being given to find; to find the Directions required to hit that Point.

Let the Perpendicular GP be erected from the Point G to G D; because G D, D B are given, the Angle DGB, and consequently the Angle B G P is given. Let the Angle B G P be bisected by the Line G N meeting D B produced in N. Now if the Points F and N coincide, G N will be the Direction sought (*by Cor.* 3. *Prop.* XI.) If the Point N falls above F, the Point B cannot be hit at all with a given Parameter or a given Force (*by the same Cor.*) But if the Point N falls below F; from the Point F let F R be erected perpendicular to D F, meeting GN produced in R; let the Line G R be bisected in S, and from the Point S let S C be erected perpendicular to GR, meeting F R produced in C. On the Center C, with the Distance C R, let a Circle be described, cutting B D produced to K and L, and if GK, GL be drawn, they will be the Directions sought. For it is evident from the Construction, that F L and F K are equal, and that the Angles L G R, R G K are equal also; whence the rest are manifest from *the 6th Corol. of the preced. Prop.* Q. E. J.

The same demonstrated another Way. From the Point F let FC be erected perpendicular to D F and equal to B G; and on the Center C, with the Distance BF let a Circle be described cutting BD produced in the Points K and L; Then G K and G L will be the Directions sought.

Tab. XXIV. Fig. 4.

For CKq — FKq that is, BFq — FKq (*by Construction*) is equal to CFq or BGq. Therefore as BF — FK or BK is to BG; so is BG to BF + FK or BL. therefore the Triangles KBG, LBG are similar; (*by Prop.* 6. *Book* VI. *of Euclid*) therefore the Angles K G B, B LG are equal; that is, if G P be erected perpendicular to G D, the Angles K G B, L G P will be equal: Therefore if the Angle B G P be bisected as before by the Line GN, the Angles L G N, N G K will be equal: Therefore (*by Corol.* 6. *Prop.* XI.) G K, G L are the Directions sought. Q. E. J.

Coroll. I.

From the former Construction there flows an Arithmetical Rule of solving the same Problem; viz. putting S for the Sign of the given Angle BGP, and V for its versed Sine; $V\frac{GD}{DF}S$. will be equal to the versed Sine of the Difference of Elevations, or of the Angle L G K. The half of which Angle, if it be added to and substracted from the given Angle D G R or half its Supplement, to two Right Angles B G P, the Sum and the Difference will be D G L, D G K the Angles sought.

Tab. XXIV. Fig. 2. and 3.

For D F or GP is the Sine of the Arch R K G, that is, of double the Angle R C S; that is, (because of the common Complement P R G) of double the Angle P G R, or (*by Construct.*) the Angle P G B. And P R is the versed Sine of the same Angle; and PR—PF the versed Sine of the Arch K R or of the Angle LGK. And it will easily appear that the Angle R G D is half the Supplement of B G P to two Right Angles. Whence the Reason of the Rule is evident.

Coroll. II.

From the same Construction flows also another Arithmetick Rule, by which G D, the Angle B G P, and either of the Elevations D G K or D G L, being given, the Parameter is found; for if B G P is given, R G D is given also; from whence D G K or D G L being given, R G K is given. Let v be the versed Sine of double R G K, and $\frac{S}{V-v}$ G D, will be

Fall, without making it move faster than it did before. Thus for Instance, If two Men of equal Bigness should join

be equal to half the Parameter. The Reason of this Rule is the same as the former.

Another Way. R G D and one of the Elevations being given, the other of them is given. Wherefore as the Radius is to half the Sum, in one Case, and half the Difference in the other Case of the Tangents of the given Elevations; so is GD to half the Parameter. For DF, or half the Parameter is equal to $\frac{DL \pm DK}{2}$ by *Cor.* 1. *Prop.* XI.

Tab. XXIV. Fig. 2. and 3.

Concerning this whole Matter, see the famous Dr. *Halley*'s Differtation, in the *Philosophical Transactions*; and the learned Dr. *Keil's Physicks*, where you will find most of these Things largely demonstrated in another Way.

Of heavy Bodies falling in a Cycloid.

The Propositions *concerning the Descent of Bodies in a Cycloid* first found out and demonstrated, by the famous Mr. *Hugens*, which depend upon the forementioned Law of Gravity; may very conveniently be added in this Place.

Lemma I.

Let there be a Circle described on the Diameter A C, which is cut at right Angles by D E; from the Point of the Diameter A, let the straight Line A B be drawn, meeting the Circumference in B, and DE in F, and let AB be joined. I say, AB, AD, AF are continual Proportionals.

Tab. XXV. Fig. 1.

For if B D be drawn; the Triangles ADB, ADF, are similiar, because the Angle A is common, and the Angles AB D, AD F, are equal, because they stand upon equal Arches AD, AE. Whence the Proposition is evident.

Lemma II.

Let there be any Curve A H concave on one Side, and let A G be a Tangent to it in the Point A. Let A D be a straight Line, any ways inclined to this Tangent, and let B C, parallel to A D, cut the Curve in B, and the Tangent in C. I say, if the Arch A B be infinitely small, that Arch and the Part of the Tangent, intercepted between the Parallels A D, BC, may be looked upon as equal and coincident, and may therefore be put for each other.

Tab. XXV. Fig. 2.

Let another straight Line touch the Curve in the Point B also, which meeting the other in E, let it be any ways produced, let F G be drawn parallel to B C, meeting each Tangent produced in the Points F and G; and let A B, the Subtense of the Arch be drawn.

It is manifest; that the Subtense A B is always less than the Arch, and the Sum of the Tangents AE, E B, is greater; now if the Point B be conceived to approach to A, and during that Motion the Line B C is carried always parallel to it self; it is manifest that the Angle BEC will be perpetually diminish'd, till it becomes less than any given Angle whatsoever; and by that Means the point F will approach nearer to G than any given Distance whatsoever, and therefore the Lines E F, E G, will be nearer to Equality than any given Difference, whatsoever: That is, E F and EG may at last be accounted as equal. Therefore EB and EC (whose Ratio to each other is the same as E F to EG, *because of the similar Triangles* EBC, EFG) and also A E + E B and A C (A E being added to each of them) may be esteemed equal likewise. In the same manner, may it be shewn also, that the straight Lines AB, AC, when the Point

join Hands and leap together from the Top of a Bridge into the River; we have no Reaſon to think that they would

Point B approaches to A, may at laſt be accounted equal alſo; And much more therefore may the infinitely ſmall Arch AB, which is of an intermediate Magnitude betwixt the Subtenſe AB, and the Sum of the Tangents AE, EB, and the Tangents AC be accounted equal.

That the infinitely ſmall Arch and the Tangent may be looked upon as coinciding, is evident from hence; that from the Nature of Curvature, there can be no ſtraight Line drawn between the Tangent and the Curve at the Point of Contact.

Prop. I.

Tab. XXV. Fig. 3.

Let ABC be a Semicycloid deſcribed by the generating Circle AVD; Let its Vertex A be turned downwards, and its Axis AD be erected perpendicular to the Horizon. Let any Point B be taken in it, and the ſtraight Line BI be drawn downwards from thence touching the Cycloid in B, and terminated by the horizontal ſtraight Line AI: Let the ſtraight Line FB be alſo drawn perpendicular to the Axis; and on the Diameter AF let the Semicircle AFH be deſcribed. Then through any Point M in the Curve BA, let the ſtraight Line MS be drawn parallel to BF, which will meet the Circle AHF in H, and its Diameter in S. Let alſo ſtraight Lines be drawn touching each Curve in the Points M and H. And let MN, HT, be Parts of thoſe Tangents intercepted between the two horizontal Lines MS, NR; and let OP a Part of the Tangent BI, and SR a Part of the Axis DA, be included between the ſame Parallels.

Theſe Things being ſo; I ſay, the Time in which a heavy Body will run through the ſtraight Line MN with an equable Celerity, ſuch as is acquired in falling through the Arch of the Cycloid BM; is to the Time that the ſtraight Line OP would be run through with an equable Celerity, ſuch as half that which is required in falling through the whole Tangent BI; as the Tangent HT, is to the Part of the Axis SR.

Demonſt.

From the Point A to the Points V and L, in which the Parallels BF, MS cut the generating Circle, let the ſtraight Lines AV, AL be drawn cutting the Parallels MS, NR in the Points K, E, G; let AH and FH be joined, and the Radius QH of the Circle AFH be drawn.

Now becauſe the Spaces run thro' with an equable Motion, are in the Ratio compounded of the Times and the Velocities with which they are run through; it follows, that the Times are to each other in a Ratio compounded of that of the Spaces directly and the Velocities inverſely. The Time therefore of running through MN, to the Time of running through OP, is in a Ratio compounded, of the Ratio of MN to OP, and of the Ratio of half the Celerity acquired by falling through AF; to the Celerity acquired by falling through FS (*by the Hypoth. and by Prop.* IV. *and Coroll. Prop.* VI. *above, concerning the Deſcent of heavy Bodies.*) Now the whole Velocity acquired in falling from F to A, is to the Velocity acquired in falling from F to S, as FA to FH, (*by Prop.* 31. *Book* III; *and Prop.* 8. *Book* VI. *of* Euclid; *and Prop.* II. *above, concerning the Deſcent of heavy Bodies.*) Half the Velocity therefore, acquired in falling from F to A, is to the Velocity acquired from F to S, as FQ to FH. The Ratio therefore of the forementioned Times, is compounded of the Ratio's of MN to OP, and FQ to FH. But (*by the Nature of the Cycloid*) BI is parallel to AV, and MN to AL, and therefore GL and KE are equal to MN, OP.

would fall quicker because they are thus joined together, than if they had leaped in separately. This being supposed; since

OP. Wherefore the forementioned Ratio, is compounded of the Ratio of GL to KE, and FQ to FH. But GL is to EK, as AL to AE, that is, as AV to AL, (*by Lem.* 1.) that is, as $\sqrt{AF \times AD}$ to $\sqrt{AS \times AD}$, that is, as $\sqrt{AF}$ to $\sqrt{AS}$, that is as AF to AH, that is, as FH to HS. The Ratio of the forementioned Times therefore, is compounded of the Ratio's of FH to HS, and FQ to FH, that is, the Times are to each other as FQ or QH to HS. But it may easily be made appear *from Prop.* 18. *Book* III. *and Prop.* 2. *and* 8. *Book* VI. *of Euclid*, that QH is to HS, as HT to SR. The Times therefore of moving through MN, OP, with the forementioned Celerities, are to each other as HT to SR. Q. E. D.

Prop. II.

Suppose the Position of the Cycloid; the Line BF, AF, BI, AI; and the Semi-circle FHA; the same as in the foregoing Proposition: I say, the Time of moving through the Tangent BI with the equable Celerity of half that which is acquired in falling through BI, is to the Time of Descent thro' the Arch of the Cycloid BA, as the Diameter of the Circle, is to half its Periphery.

Tab. XXV. Fig. 4.

Demonst.

Suppose as many parallel Lines as you please, equidistant from each other to be drawn between FB and AI, which will cut the Line FA in S, R, &c; the Circle in H, i, &c. and the Cycloid in M, r, &c. its Tangent BI in O, P, &c. And from the Points where each of them intersect the Circle and the Cycloid, let the Tangents to each Curve, HT, MN, ik, rs, be drawn to the following Parallel, as in the Figure.

The Time of moving through OP equably with half the Celerity acquired in falling through BI, is to the Time of moving through MN, equably with the Celerity acquired in falling through the Arch of the Cycloid BM; as SR to HT; And the Time of moving through PQ with the same Celerity as through OP; is to the Time of moving through rf with the Celerity acquired in falling through the Arch of the Cycloid Br, as RE to ik, and so on, (by the preced. Prop.) Therefore since every one of the equal Times of the equable Motions, through the equal Lines OP, PQ, *&c.* (*by Construct.*) are referred to so many other Times of Motion, *viz.* through the Tangents of the Cycloid MN, rf, &c. in the same Proportion, as the equal Lines SR, RE are each of them referred to the Tangents of the Circle HT, ik &c. The Sum of the former Times will be to the Sum of the latter Times; as the Sum of the former Lines to the Sum of the latter Lines. Let therefore the Number of the parallel Lines lying between FB and AI be infinite, and let the Tangents to each Curve be drawn in the same Manner as before, and the Proportion will continue the same. And as by this Means the Sum of the Tangents of the Circle will coincide with its Semiperiphery FHA, and the Sum of the Tangents of the Cycloid will coincide with its Arch BA; and the Motion through the infinitely small Arch of the Cycloid contained betwixt the two contiguous Parallels, may be conceived to be the same as that which was supposed through the Tangents: (*by Lem.* 2.) It follows; that the Time of Descent through BI with the forementioned Celerity, is to the Time of Descent through the Arch of the Cycloid BA; as the Diameter FA is to its Semiperiphery FHA. Q. E. D.

Prop.

ſince it is certain that the different Parts of a heavy Body, are as ſo many ſimilar Bodies, none of which have

Prop. III.

In a Cycloid whoſe Axis is perpendicular to the Horizon, and whoſe Vertex is turned downwards; the Time in which a heavy Body let fall from any Point of it, will arrive at the Vertex, is to the Time in which it would fall through the Axis of the Cycloid, as half the Circumference of the Circle, is to the Diameter: And therefore the Times in which a heavy Body let fall from any Points whatſoever will arrive at the Vertex, are equal to each other.

Let ABC be a Cycloid, A the Vertex turned downwards, AD the Axis perpendicular to the Horizon; And let a heavy Body be let fall from any Point B; Let BI be a Tangent to the Point B, meeting the horizontal Line AI in I; and from the ſame Point B, let the Line BV be drawn parallel to CD, meeting the generating Circle in V, and let AV be joined.

Tab. XXV. Fig. 3.

The Time of Deſcent through the Arch of the Cycloid BA, is to the Time of Deſcent in the Tangent BI with an equable Celerity equal to half that which it would acquire in falling through BI; as half the Periphery of the Circle, is to the Diameter (*by the preced. Prop.*) But the Time of Deſcent through BI, is equal to the Time of its Deſcent by a natural Acceleration along the ſame BI, (*by Prop. III. of the Deſcent of heavy Bodies*) or along VA, which is parallel and equal to BI: (*by the Nature of the Cycloid.*) And the Time of Deſcent along VA, is equal to the Time of Deſcent along DA; (*by Prop. V. of the Deſcent of heavy Bodies.*) Therefore the Time of Deſcent along the Arch BA, is to the Time of Deſcent through the Axis DA; as half the Periphery of the Circle, is to the Diameter.

And ſince the Time of falling through the Axis is given; and has the ſame Proportion to the Times of Deſcent through any Arches of the Cycloid to the Vertex; it is evident that all thoſe Times of Deſcending muſt be equal to each other. Q. E. D.

Coroll.

It is manifeſt, that when the heavy Body comes at the Vertex, its Motion continuing, it muſt in aſcending deſcribe an Arch of the Cycloid in the ſame Time, equal to that deſcribed in deſcending; So that the Time of its whole Motion, will be to the Time of its Deſcent through the Axis, as the Circumference of a Circle to the Diameter. *See Hugens's Horol. Oſcil. Part* II. *from Prop.* 16. *to the End of that Part.*

The Equality of the Times in which a heavy Body, let go from any Point of a Cycloid, comes to the Vertex of it, may alſo be demonſtrated in the following Manner.

Let a Body be impelled in the Line AC, towards the Center C, with an accelerative Force, which is every where as the Diſtance from C. I ſay, that from what Point ſoever of the Line AC, the heavy Body is let fall, it will come to the Center C in the ſame Time.

Tab. XXVI. Fig. 1.

Suppoſe any Line ac unequal to AC; and let either of them, as AC be divided into as many equal Parts as you will, AB, BG, GC: Let the other Line ac be divided into as many equal Parts, ab, bg, gc. Let us imagine the ſuppoſed Force to act only in the Beginnings of theſe Parts, ſo that each of them may be run through with an equable Motion. And let two Bodies, impelled by that Force, begin to be moved together, from the Points A, a, towards C, c. Now becauſe the Celerities with which the Parts AB, ab, are run through, are as the Forces with which the Bodies are impelled in the Points A, a; And theſe Forces are to each other (*by the Hypoth.*) as AC to ac, or as AB to ab; Therefore AB, ab, will be run through in the ſame Time. Let the accelerative Force act

have more Tendency to descend quicker than the other; we must conclude that they will all descend together with the

act again with a second Impulse in the Points B, b: And because the Increments of the Celerities are proportionable to the Impulses, or to the accelerative Forces, that is, to the Lines, BC, bc; (*by the Hypoth.*) or to AC, ac; or to the Celerities generated by the first Impulse, the whole Celerities after the second Impulse, will be proportionable to the Celerities after the first Impulse; therefore the Lines BG, bg, equal in Proportion to the former, will be run through in the same Time. For the same Reason the Lines GC, gc, will be run thro' in the same Time, after the third Impulse. Let the Number of equal Parts in the Lines AC, ac, be increased infinitely, and consequently their Magnitude diminished in the same Manner; so that the Bodies may be continually impelled by the supposed Law of Acceleration; and the same Reasoning will hold good. Wherefore in this Case, the Times of Descent through AC, ac, are equal. Now let ABC be a Cycloid, whose Axis AD is perpendicular to the Horizon, its Vertex A turned downwards, and the generating Circle AHD. Let the heavy Body be placed in any Point of it, as B; and let BG be drawn perpendicular to the Horizon, BF a Tangent to the Cycloid in the Point B, and FG a perpendicular to the Tangent; so as that they may form the Triangle BGF. Let the Force of Gravity, whose Direction is according to the Line BG, be resolved into two other Forces BF, FG; of which two Forces, it is the Force BF only by which the heavy Body is impelled in the Point B to descend in the Cycloid; the other Force FG is taken off by the Resistance of the Tangent or Curve. Now if BH be drawn parallel to CD, and meet the generating Circle in H and AH, DH be joined; then because BF is parallel to AH (*by the Nature of the Cycloid*) and BG parallel to DA (*by Construct.*) and the Angles F and H Right Angles, therefore the Triangles BFG, AHD, are similar. Wherefore, as BF is to BG; that is, as the Force with which the heavy Body is impelled in B, is to the Force of Gravity; so is HA, to AD. Wherefore because the Force of Gravity is given; the Forces with which the heavy Body is impelled in every Point of the Curve, are to each other, as the Lines AH, that is, as the Arches of the Cycloid AB, which (*by the Nature of the Cycloid*) are double the Lines AH. The Forces therefore with which a heavy Body descending through the Arch of a Cycloid, is impelled, are as its Distances from the Vertex A. Wherefore from what Point soever it is let fall in it, it will come to the Vertex in the same Time. Q. E. D.

Tab. XXVI. Fig. 2.

Prop. IV. *A Problem.*

To make the Vibrations of a given Pendulum to be all performed in the same Time; or to make a Pendulum vibrate in a Cycloid.

Let CF the given Length of a Pendulum, be perpendicular to the Horizon; which being bisected in G, and DCI drawn perpendicular to it through C; let two Semi-cycloids be described from the Point C, by a generating Circle, whose Diameter is CG, and let their Bases be CD, CI, and their Vertexes A, N. Let AN be joined, which will be parallel and equal to DI, and will therefore be the Base of a whole Cycloid described by the same generating Circle as CBA, CN. Let this Cycloid be AFN. Now if a heavy Body be hanged in F upon a Thread CF or any such Thing which will bend; and so oscillate upon the Center C between the Semicycloids, CBA, CN, that whenever it moves from the Perpendicular, the upper Part of the Thread may bend upon that Cycloid towards which the Motion is made, and the remaining Part which is not applied to the Cycloid, be stretched out in a straight Line; I say, the heavy Body will always be found in the Cycloid AFN.

Tab. XXVI. Fig. 3.

Demonst.

the same Celerity that any one of them would: From whence it evidently follows; that a heavy Body of a

Demonstration.

Let the generating Circle of the Cycloid A F N be described on the Axis G F; and from the Point E where the heavy Body is, when removed from the perpendicular, let E L be drawn parallel to A G, meeting that Circle in L, and let G L be joined. From the Point B, (in which the Thread E B touches the Cycloid C B A, the remaining Part being bent upon the Arch C B) let B H be drawn parallel to A G also, meeting the generating Circle A H D in H; and let A H be joined.

The whole Length of the Thread C B E, is equal to twice A D; (by *Construction.*) Therefore it is equal to the Semicycloid C B A; (*by the Nature of the Cycloid*) and the part of the Thread C B is equal to the Arch CB, to which it is applied: Therefore the remaining part of it B E, is equal to the remaining Arch B A, and is therefore equal to twice the straight Line AH; (*by the Nature of the Cycloid*) It also touches the Cycloid in B; therefore (*by the Nature of the Cycloid*) it is likewise parallel to A H; Therefore AH and BK are equal, and therefore B K and K E are equal also: Therefore the parallels E L and B H are equally distant from A G; Therefore they cut off equal Arches of the generating Circles, *viz.* G L equal to A H and L F equal to HD: Therefore G L and A H are parallel; and therefore G L and K E are parallel; and therefore E L is equal to K G. But KG (*because of the parallels H A, K B, and by the Nature of the Cycloid*) is equal to the Arch HD, that is, to the Arch LF; therefore EL is also equal to the Arch LF; Therefore (*by the Nature of the Cycloid*) the Point E is in the Cycloid AFN. Q.E.D.

Coroll. 1.

Since it appears that the Extremity E, of a Pendulum vibrating between the two Cycloids C A, C N, describes the Cycloid A F N equal to either of them; and from its so describing it, it is manifest, that the very small parts of the Curve taken on each Side the Vertex F, do nearly coincide with very small parts of the Circle taken on each Side the same Point F; Hence it follows, that the Times of the smallest Vibrations of a Pendulum oscillating in a Circle, are also very nearly equal to each other; and have very nearly the same Ratio to the Time of the perpendicular Fall through half the Length of the Pendulum; as the Circumference of a Circle has to its Diameter.

Coroll. 2.

Hence also appears a Method of determining *the Space thro'* which a heavy Body runs, in falling perpendicularly, in a given Time. For the Ratio of the Time of one Oscillation, to the Time of *the Fall through* half the Length of the Pendulum, is given. By finding therefore the Time in which a Pendulum of any given Length performs a single Vibration; the Time of falling through half the Length of the same Pendulum, is given. Whence (*by Prop.* II. *of the Descent of heavy Bodies*) the Space which it will run thro' by falling, in any other given Time, is collected.

Coroll. 3.

Hence also may be found a Method of determining an universal and perpetual *Measure of Magnitudes.* For the Law of Gravitation, upon which the foregoing Propositions depend, being allowed; a Pendulum of the same Length, will always and in all Places, perform some certain Number of Vibrations, in a given Time. This Length therefore may be made an universal and perpetual Measure, because it can always be determined by Experiments. Whence it follows, that having once determin'd the Proportion which the *Measures of the Magnitudes,* in any Nation, bears to that Length; what the Quantity of those Measures is, is easily know at any time. Now the Length of that Pendulum may be determined, by observing how many Oscillations, in that given Time, another Pendulum of any Length, performs. For the Lengths of Pendulums are to each other, as the Squares of the Times in which a single Oscillation is made; (*by Prop.* III. *preced. and Prop.* II. *of the Descent of heavy Bodies*) and therefore they are reciprocally as the Square of the Number of Oscillations made in the same Time. See *Hugenius's Horol. Oscil. Par.* 4. *Prop.* 25. *and* 26.

 hundred

hundred pound Weight, for Example, will not defcend quicker than another Body which weighs but one Pound; or that if there be any difference, it is imperceptible. And this is confirmed by Experience, contrary to the Opinion of *Ariftotle* and a great many other Philofophers, who were perfuaded, that the heavier a Body is, the quicker in Proportion does it fall.

CHAP. the Laft.

Of the Flux and Reflux of the Sea.

1. What is meant by the Flux and Reflux of the Sea.

THAT which we call the Flux and Reflux of the Sea, is a particular Motion of its Waters, which is found to be regular and certain, though the Time and Manner is not the fame in all Seas.

2. That the Sea flows about Six Hours about the Coaft of France.

2. We obferve upon the Coafts of *France*, that the Water of the Sea runs at certain Times from South to North; which Motion is called the *Flux* of the Sea; it continues about Six Hours, during which Time, the Sea fwells gradually, and rifes upon the Coaft entering into the Channels of the Rivers, and forcing the Waters back towards their Springs.

3. That the Sea ebbs for the fame Space of Time.

3. After thefe Six Hours in which the Sea continues to flow; it feems to ftand ftill for about a quarter of an Hour; and then it changes its Courfe and runs from North to South for Six Hours more; during which time the Waters on the Coaft abate, and thofe in the Rivers go in their ufual Courfe as their Channels direct them. This Motion is called the *Reflux* of the Sea; after which it feems to ftand ftill again for about a Quarter of an Hour, and is then fucceeded by a Flux and after that a Reflux as before.

4. That the Tide is about fifty Minutes later every Day than another.

4. Thus the Sea is obferved to rife and fall twice every Day; but this does not happen exactly at the fame Time, becaufe it takes up more than twelve Hours from one Flux to another; and if we would know exactly how long Time it takes up; we muft obferve it a great many Days together, and then it will appear, that the Flux of it falls about fifty Minutes later every Day than other. So that if we fuppofe the Sea begins to rife any Day at Noon, it will not begin to rife exactly at the fame Time the next Day, but about fifty Minutes later, that is, three Quarters of an Hour and five Minutes later.

5. Now because there is just the same Difference of Time in the Moon's being in the Meridian one Day, and the Day following; we may affirm that the Sea rises as often as the Moon passes through the Meridian, as well below as above the Horizon; and also that it falls as often as the Moon is in the Horizon, as well when it sets, as when it rises.

5. That the Sea rises and falls, as often as the Moon is in the Meridian and in the Horizon.

6. We observe also another constant Agreement betwixt the Moon and the Sea; and that is, that though the Sea increases every Day, it does not increase every Day alike; but the Tides are so much the greater as the Moon draws nearer to its Conjunction or Opposition, and so much the less, as it is nearer the Quadratures.

6. That the Tides are greater at the New and Full Moon than in any other Part of the Month.

7. Lastly, The Increase of the Sea is sensibly greater at those new and full Moons which happen nearest the Equinoxes than in any other part of the Year.

7. That the Tides are greatest of all near the Equinoxes.

8. Very near the same Thing hath been observed in all the Coasts of *Europe* that are upon the main Ocean; but the Flux is so much the greater, and happens so much the later, as the Coast on which it is, is more northerly; and on the contrary it is least of all and scarce sensible between the two Tropicks.

8. How the Tides are made upon particular Coasts of the Sea.

9. The *Mediterranean* Sea does not swell at all, except at the Bottom of the Gulph of *Venice*, that is, at *Venice* itself and the Neighbouring Places; every where else there is nothing to be seen, but the common Motion along the Shore.

9. How it is in the Mediterranean.

10. The *Baltick*, the *Euxine* Sea, and the *Dead Sea* in *Asia*, have no Flux or Reflux at all.

10. That in some Seas there is no Tide at all.

11. Notwithstanding what some have writ about the *Euripus*; it is very certain, that nothing else is to be perceived in all the *Archipelago*, but particular Currents of Water, which sometimes go North and sometimes South, without swelling, and without observing any certain Rule.

11. That the Tides in the Archipelago *are very uncertain.*

12. As to what the Tides are in other Seas, the Accounts which we have are so very imperfect, that we cannot at all depend upon them.

12. That the Tides are very uncertain in other Parts of the Sea.

13. After all these Observations which have been confirmed by the continual Experience of many Ages, I shall not throw away the Time in needlessly relating and confuting the different and whimsical Opinions of the antient and modern Philosophers, about the Flux and Reflux of the Sea; but I shall endeavour to deduce this Motion directly from its true Cause, and to account

13. The particular Figure of the Earth's Vortex.

Tab. XIV. Fig. 2.

 for

for all the different Obſervations. Let us ſuppoſe then, that in the following Figure, the Oval A B C D repreſents the Vortex, in the Center of which is the Earth E F G H. The Circle A L repreſents the Body of the Moon; The Line A C the Place where the Moon is at the Time when it is New or Full; and the Line BD that where the Moon is in it Quadratures.

14. That the Place of the Earth which is directly under the Moon, is moſt preſſed upon by the fluid Matter. Tab. XVII. Fig. 2.

14. Now, if we imagine the whole fluid Matter, which ſurrounds the Earth, and reaches from the Surface of it, further than the Moon, to be divided into a great many Strata, or Beds; we ſhall ſee that that which is about N having but a ſmall Circuit to make from Weſt to Eaſt, will finiſh its Revolution almoſt in the ſame Time as the Earth; but the Matter which is in Q, will take up more Time to finiſh its Revolution, and the Matter in O will take up ſtill more. Further, if we go on to imagine the Matter, which is contained between the two Superficies M L, D A, by which the Moon is carried about the Earth, to be divided into two Parts; one of which is below the Center of the Moon marked I, and conſequently nearer us, the other above its Center; we ſhall ſee, that the Matter which is below, and which correſponds to that half of the Moon which looks towards us, moves quicker from Weſt to Eaſt, than the Matter which is higher; ſo that the Moon being carried along by a fluid Matter, ſome Parts of which move ſwifter than others; its Celerity muſt be a Medium betwixt that of the higheſt and that of the loweſt fluid Matter. All the Matter therefore which is in the Space O P, which is on this Side the Moon, moves ſwifter than the Moon itſelf from Weſt to Eaſt, and comes ſooner to the Space E L, where its Paſſage being ſtraightned by the Hemiſphere of the Moon, it is forced to run ſwifter than in any other Place: And becauſe all Bodies, the ſwifter they move, the greater Impreſſion do they make upon other Bodies againſt which they preſs; it is evident that the whole Matter which moves about the Earth, ought to preſs more upon it in that Part which is directly under the Moon, than in any other Place.

15. That it ought alſo to preſs equally upon the oppoſite Point.

15. Moreover, ſince it is certain that there is nothing to ſupport the Earth, but its Place is determined wholly by the equal Preſſure of the Matter which incompaſſes it; therefore we cannot imagine but that if that Part of the Earth which is directly under the Moon, be more preſſed upon than any other Part, it will cauſe the Earth to move a little out of its Place, and to go ſo far towards

wards R, which is on the oppoſite Part of the Earth to the Moon, till the Place G is as much preſſed upon by the fluid Matter againſt which it moves, as the Place E is by the Air which is forced upon it.

16. An Explication of the Flux and Reflux of the Sea upon the Coaſts of France.

16. The Air therefore preſſes upon the Places E and G as if it was heavier there than any where elſe; and becauſe theſe Places are within the Torrid Zone; it follows, that if there be any large Sea there, the Preſſure of the Air, muſt cauſe a Motion in the Waters of it, from the Equator towards the Poles. Now the Ocean extends itſelf over the greateſt Part of the Earth, and reaches from the South almoſt as far as the North Pole. The Water therefore of the Ocean which is near the Equator, ought to flow from South to North, and to beat upon the Shore; and becauſe the Waves which go firſt, are ſupported by them that follow, the Sea muſt ſwell in thoſe Places. And afterwards, when by the Earth's turning, the great Preſſure remains no longer upon the Place where it was; the Waters will ſubſide by their own weight into the Place which they were forced out of, ſo that the Sea muſt then decreaſe upon the ſame Coaſts.

17. Why it happens twice every Day.

17. That Part of the Ocean whoſe Waters are forced upon our Shores, is once every Day directly under the Moon, and once oppoſite to it; wherefore the Sea ebbs and flows twice every twenty-four Hours.

18. Why it is fifty Minutes later every Day than there.

18. If the Moon had not the Motion which it now has from Weſt to Eaſt, the Flux and Reflux of the Sea would happen every Day exactly at the ſame Time, and alſo twice a Day; becauſe the Earth by turning about, would bring the ſame Place of the Ocean directly under the Moon, every twenty-four Hours, which twelve Hours before, was in the oppoſite Side to it: but becauſe the Moon advances twelve Degrees and a half towards the Eaſt every Day, it follows, that when the Earth has gone round, it muſt go twelve Degrees and a half more before the ſame Place in its Superficies will be under the Moon again. And this is the Reaſon why the Flux of the Sea happens fifty Minutes later every Day, and that there is five and twenty Minutes Difference between the Time of one Flux and that immediately ſucceeding.

19. Why the Tides are ſo much the later and ſo much the bigger, the more northern the Coaſts are.

19. It is further evident, that one and the ſame Tide ought to happen later, the more northern the Coaſt is; becauſe, the Water flowing from South to North, the Swelling muſt firſt be perceived in thoſe Places which are

are neareſt: And, becauſe the Water which runs along the Coaſts which are about the Torrid Zone, have a free Paſſage towards the Poles, and are no where hindred till they come to the northern Coaſts; hence it is that the Flux of the Sea is ſo much the greater, the more remote any Place is from the Equator.

20. Why the Tides are bigger at the New and Full Moons. Tab. XIV. Fig. 2.

20. When the Moon is at the New or Full, then its Place is in the Diameter A C, which is the leaſt Diameter of the Earth's Vortex; and becauſe the Diameter of the Earth, bears a greater Proportion to the Diameter AC, than it does to the Diameter BD where the Moon is in the Quadratures; therefore at thoſe Times it muſt neceſſarily cauſe the Air which incompaſſes the Earth to be conſiderably more compreſſed than at any other part of the Month; and ſo the Waters muſt be driven towards the Poles with greater Force; whence it follows, that the Tides ought to be bigger at the New and Full Moons than at the Quadratures.

21. Why they are biggeſt near the Equinoxes.

21. When the Moon is in Conjunction or Oppoſition to the Sun, near the Times of the Equinoxes, it is then in the Beginning of the Signs *Aries* or *Libra*; and becauſe the Circle which it deſcribes at this Time, correſponds to the Equinoctial Circle, and conſequently is the largeſt that it can deſcribe about the Earth; therefore it muſt preſs upon the Air, and force that more perpendicularly upon the Earth than at any other Time: And this Action or Impreſſion upon the Waters muſt add ſomething to the Effect which the Moon generally has at the New or Full; ſo that the Waters ought at thoſe Times to be driven with a greater Force, and in a more than ordinary Quantity againſt our Coaſts, and thereby increaſe the common Effects produced by the Moon; that is, make greater Tides.

22. That the Winds cauſe Irregularities in the Tides.

22. If we add to what has been already ſaid concerning the Tides, that the Winds may ſometimes conſpire with and accelerate the Motion of the Water, and at other Times be contrary to and retard it; we ſhall have an exact Explication of all the Particulars which Seamen have obſerved concerning this Phænomenon, which has at all Times been eſteemed very difficult.

23. Why the Moon when it paſſes over ſeveral Rivers and Lakes, cauſes no Fluxes and Refluxes in them.

23. But in order to determine ſomething of what ought to be in other Places; we muſt conſider that the Motion of the Waters of the Sea, depends upon this; that in a large and vaſt Extent of Sea, there are ſome Places which are very much preſſed upon by the Moon, and others which are not preſſed upon at all; and this

makes

makes the Waters ſpread themſelves to thoſe Places where they are not preſſed upon. If therefore there be any Waters which are but of a ſmall Extent, though the Moon preſſes upon the whole of them, yet becauſe that Preſſure is every where alike, they can neither riſe nor fall. Now the Rivers and Lakes which are between the Tropicks are ſuch Sort of Waters as theſe; the Extent of them is very inconſiderable, compared with the Body of the Moon which paſſes over them; and therefore we do not find any Flux or Reflux in them.

24. Why ſeveral Seas have no Flux or Reflux.

24. As to thoſe Lakes and Rivers which are beyond the Tropicks, there is ſtill greater Reaſon to believe that they ought not to have any Tides at all; neither ought the Seas there to have any, unleſs they have ſome Communication with the Ocean, and not then unleſs the Paſſage be very ſtraight: For the Moon never paſſes directly over theſe Waters, and therefore they cannot be preſſed by it: Wherefore we are not to think it ſtrange that the *Dead Sea* in *Aſia*, and the *Euxine* Sea, and the *Baltick* in *Europe* have no Flux and Reflux.

25. Why there is no Tide to be perceived in the Mediterranean *Sea.*

25. The *Mediterranean* Sea, which is beyond the Tropick, has indeed a very free Communication with the Ocean by the Streights of *Gibraltar*: But becauſe this Paſſage is not above three or four Leagues over, it is a very inconſiderable Quantity of Water only that can enter in ſix Hours, if we conſider the Depth and Extent of this Sea. Further; no ſooner do theſe Waters advance, but they meet with a wider Sea, the Coaſts of which are ſo diſpoſed, as to make the Water glide along by the Land only: So that we obſerve only a ſimple Motion or Current of Water in the *Mediterranean*, without any ſenſible Swelling.

26. Why one Water riſes and falls at Venice.

26. However, the Waters which enter into the Gulph of *Venice*, after having glided along the Coaſt, ought at laſt to come to the Bottom of the Gulph, where by falling upon and ſupporting each other for ſome Time, they muſt increaſe in the ſame Manner as the Ocean does, only they cannot riſe to ſo great a Height.

27. That there ought not to be any Increaſe of the Water in the Archipelago.

27. As to the *Archipelago*; That is at ſuch a Diſtance from the Streights of *Gibraltar*, and is withal ſo interrupted by the Iſlands which divide the Water, that it cannot receive any Quantity of Water ſufficient to make it ſwell; for which Reaſon, we ought not to perceive any Flux or Reflux there, as we do in the Gulph of *Venice*; and this is confirmed by Mariners who frequent this Sea.

28. The Cause of the Motion of the Waters in the Archipelago.

28. It is very true, that there are Currents of Water seen in this Sea, which moves sometimes South and sometimes North, without observing any Rule: But there is Reason to think that the Cause of the Motion of these Waters towards the South is this; that the *Euxine* Sea, which is but of a small Extent, is continually receiving the Waters of a great many large Rivers, which it discharges itself of by the *Archipelago* into the *Mediterranean:* And that which causes the Motion of them towards the North, is the South Wind, which blows so very strong sometimes, as to drive the Water back, and to support it, till the Quantity of it is become so great, that its own Weight forces it to go in its usual Course.

29. If there be any other Particulars remaining, they may be comprehended in what has been already said.

29. There may be some other Particulars observed concerning the Flux and Reflux of the Sea, besides those already mentioned; but whatever they be, the Reason of them will be found to be comprehended in what has been before said: For when [1] the principal Difficulty is once got over; the same Foundation upon which that has been cleared, will of Necessity give Satisfaction in all other Circumstances which depend upon particular Causes.

Having

1 *The principal Difficulty is once got over,* &c.) The universal Gravitation of Matter being allowed; so that the Earth gravitates towards the Moon and the Moon towards the Earth, and all the Parts of them towards each other; the Phænomena of the ebbing and flowing of the Sea is very clearly explained by the learned Dr. *Hally,* from the Principles of the famous Sir *Isaac Newton*; the principal Heads of whose Dissertation upon this Subject, I shall here briefly explain.

First then, since the Superficies of the Earth and Sea is round of it self if the Moon A be perpendicularly over any Part of the Superficies of the Sea, as E; it is evident that the Water in E, which is nearer the Moon, than any other Part of the Earth and Sea in the Hemisphere FPH, ought to gravitate more towards the Moon than any of those other Parts; so that that Water must by this Means be lifted up towards the Moon, that is, be lighter than usual and swell in E. (Tab. XIV. Fig. 2.) So likewise on the other Hand; because the Water in G, is further off from the Moon, than any of the other Parts of the Sea and Land in the Hemisphere FGH: it must gravitate towards the Moon less than any of them, that is, it ought to be lifted up the contrary Way, and to swell in G. By this Means the Superficies of the Ocean must necessarily gather itself into an oval Figure, whose longer Diameter is EG, and the shorter Diameter FH. And since it is further manifest, that the Swellings of this oval Figure ought to alter every Day, according to the Moon's Motion, it is evident that the diurnal Fluxes and Refluxes of the Sea may be most clearly explained in this Manner.

Secondly, Because at the Conjunctions and Oppositions of the Sun and Moon, the Gravitation of the Water towards the Sun conspires with its Gravitation toward the Moon; but in the Quadratures, the Water which is lifted up by the Moon, is depressed by the Sun, and that which is lifted up by the Sun, is depressed by the Moon;

Having now given a Deſcription of the World in general, and ſpoken to two or three of the principal Effects which depend upon the Compoſition of it, I come now to thoſe Parts which are nearer us, and to treat of terreſtrial Things, particularly of the Earth itſelf, and what is produced upon it.

Moon: Therefore the greateſt Tides are thoſe which are made in the Conjunctions and Oppoſitions, and thoſe at the Quadratures are the leaſt. But the Force which the Sun has to move the Sea, is much leſs than the Moon's Force; becauſe tho' it be ten thouſand Times bigger than the Earth and Moon together, yet by reaſon of its immenſe Diſtance, the Earth's Semidiameter bears no Proportion to it.

Thirdly, Becauſe about the Time of the Equinoxes, the greateſt Tides (*viz.* thoſe which are made at the Conjunction and Oppoſition of Sun and Moon,) are cauſed by the Sun and Moon when they are both in the Equinoctial; but thoſe at the Time of the Solſtices are made by the Sun and Moon when they are in the Tropicks; therefore thoſe greateſt Tides are bigger at the Equinoxes and leſs at the Solſtices: Becauſe the larger the Circle is in which the Waters revolve, the greater muſt the Agitation of them be; and if the Moon ſtood ſtill in the Pole, the Tides or the Swelling of the Waters would continue immoveable about the Poles.

Fourthly, Becauſe theſe Tides are a little altered by the Libration of the Waters, which are apt to retain the Motion impreſſed upon them, therefore the greateſt Tides of all, do not happen exactly at the Conjunction and Oppoſition of the Sun and Moon, but generally about three Tides after.

Fifthly, Becauſe the Sun is a little nearer the Earth in the Winter than in the Summer, therefore the greateſt Equinoctial Tides, are obſerved to be thoſe which happen a little before the vernal Equinox and a little after the Autumnal Equinox.

Sixthly, Becauſe in every diurnal Revolution of the Moon, the greateſt of the two Tides, ought to be that in which the Moon approaches neareſt to the *Zenith* or *Nadir*: Therefore in our Climates, when the Moon is in the Northern Signs, that diurnal Tide which is made when the Moon is above the Horizon, is a little bigger than the other; and when the Moon is in Southern Signs, the Tide which happens when the Moon is below the Horizon, is the biggeſt.

All other Phænomena of the Tides, which according to the different Latitudes of the Places, the Shallows, Bays, Streights of the Seas, and different Tides beaten back from the Shoars and meeting together are infinitely various; may be very eaſily explained by this Theory, if we have a true Notion of it in our Minds. See *the Philoſophical Tranſactions, No.* 226.

This is the Opinion of the famous Sir *Iſaac Newton* concerning the Tides, which *Kepler*, by a ſurpriſingly probable Conjecture, had ſome Notion of, before it was clearly found out. *If*, ſays he, *the Earth ſhould ceaſe to attract its own Waters to it: All the Water in the Sea would be lifted up and run into the Moon: The Sphere of attractive Vertue which is in the Moon, reaches as far as the Earth, and draws up the Waters under the Torrid Zone, &c.* See his Introduction to the Theory of *Mars*.

PART



PART III.

A TREATISE OF Natural Philoſophy, Concerning TERRESTRIAL THINGS.

CHAP. I.

Of the EARTH.

1. That we are naturally led to inquire more diſtinctly into thoſe Things which are near us, than into thoſe that are at a Diſtance.



THE Univerſe contains an infinite Number of different Things, whoſe Diſtance is ſo great as not to afford us a clear and diſtinct Knowledge, but only an imperfect and confuſed Notion of them, whereby they appear only as luminous or tranſparent. Wherefore we generally think that we have a ſufficient Knowledge

Knowledge of theſe Things, if we can find out what That is in them which is the Original or Cauſe of theſe two Qualities which we obſerve to belong to them. But it is not ſo with reſpect to the Earth, and the Bodies which are contained in it, or which are very near to it: For theſe being within the Reach of all our Senſes, we can examine them a great many different Ways, and thereby obſerve a great many Properties, each of which deſerves to be particularly conſidered. And to eſtabliſh this Knowledge, is the Deſign of this third Part of our Treatiſe of Natural Philoſophy.

2. That the Earth continually alters.

2. Daily Experience, and a thouſand Obſervations made by the Induſtry of Men in paſt Ages, and which we ourſelves have confirmed; do ſufficiently convince us, that there is no part of the Earth, be it never ſo great or ſmall, but that in Time it undergoes ſome Alteration, either from the Action of Water or Air, or of the ſubtle Matter which enters into its Pores; even Diamonds, which are the leaſt liable to Alteration of any Bodies that we know, wear away and diminiſh in length of Time, not only by rubbing againſt each other, but by mere handling them with our Hands, or rubbing them againſt our Clothes. For after we have carried them a long Time about us, they do not look ſo well poliſhed, and the angular Points of them grow blunt; which is a certain Sign that they have loſt ſome of their Parts: The Earth therefore, which has ſo long withſtood the Force of the ſubtle Matter of its Vortex, muſt long ſince have been entirely worn out and deſtroyed, or at leaſt, very much changed to the worſe from what it once was, unleſs it had been continually ſupplied and repaired from ſomewhere elſe. But ſince we are ſure that it does ſubſiſt ſtill, and that it does not appear at all different to us from what the Antients deſcribe it, this is a ſufficient Proof that it is repaired as faſt as it waſtes. And becauſe this Reparation, as well as what it loſes, depends upon the Action of thoſe Things which encompaſs the Earth, if there be any Ground to hope for a thorough underſtanding of the Nature of the Earth, it muſt be principally from our Reaſoning about what muſt be the Effects of the Action of the Matter of the Vortex, in whoſe Center it is, upon it.

3. That the Earth is made up of the Parts of the third Element.

3. Now if we conſider, that this Vortex, in turning round, muſt force the moſt ſolid and moſt agitated Parts, from the Center, it is reaſonable to conclude, that

that thoſe which remain about the Center, muſt be leſs ſolid and leſs agitated; and that therefore the Earth is compoſed of Parts of the third Element, which, becauſe they are very groſs, and of no great Solidity, and of ſuch Figures as make them apt to entangle each other, are more difficult to be moved than the others: And there is no other Difference betwixt theſe terreſtrial Parts, and thoſe which we before ſaid the Spots of the Sun were compoſed of, but this, that the Parts of the Earth are more ſtrongly and cloſely united together, and by that Means form a Denſer and more compact Body.

4. How the Parts of the Earth come to be ſo different.

4. And becauſe the Parts of the third Element are of very irregular Figures, and can therefore be ranged only in a very odd Manner; from hence ariſes all the Inequalities which we obſerve in the Earth: And this is the Reaſon why there are Mountains in ſome Places and Deeps in others; that ſometimes we meet with a great Number of its Parts ſucceeding one another without Interruption, and forming one continued Body, and at other Times, we ſee Valleys and large Caverns; Laſtly, hence it is, that ſome of its Parts are very hard, and others very ſoft.

5. Why the Earth is round.

5. However, it is to be obſerved, that notwithſtanding all theſe Inequalities, it is impoſſible but that the Earth muſt be round, or very nearly ſo; becauſe if at the Beginning, there had been any Part conſiderably higher (compared with the whole Maſs) than all the reſt, the liquid Matter which ſurrounded it, to whoſe Force it lay more expoſed than any other Parts, could not but beat with more Violence againſt, and by degrees undermine it, till it became very near upon the ſame Level with the reſt.

6. What the Reaſon of its other Properties is.

6. If then the Earth be ſuch as we have now deſcribed it, it ought to be hard and dry; becauſe the Hardneſs and Dryneſs of any Body are Qualities which are the Reſult of its Parts being at reſt; It muſt alſo be cold, becauſe there is not Motion enough in its Parts, to excite Heat: And it muſt alſo be heavy, becauſe its Parts, having leſs Force than the other Matter to go off from the Center of the Vortex in which the Earth is, muſt needs be impelled that Way. If we add to this; that the Reaſon why it is opake, is becauſe of the frequent Interruption and Winding of its Pores, which do not correſpond with each other, we may aſſure ourſelves, that this ſhort Deſcription contains a full

full Explication of the principal and moſt obvious Properties of the Earth. So that I may be excuſed adding any Thing farther upon this Head, except a little more particular Conſideration of its Pores; which ſeems to me neceſſary in order to the more diſtinct Knowledge of it.

7. It is true indeed, that it is impoſſible to deſcribe them all, becauſe of the prodigious different Sorts that there are in this large Maſs, and eſpecially, in that Part of it which we call the exterior Earth, the Particles of which are of very irregular Figures: However, if we can content ourſelves with the Conſideration of the Nature of the Pores of the interior Earth, (which muſt needs be very ſtraight, becauſe the Parts of the third Element are very much compreſſed there, by the Weight of all the Parts which they ſuſtain;) they may eaſily be reduced to theſe three Sorts. Firſt, ſuch as will *bend* and *turn* all Ways, and go along like Waves; Secondly, ſuch as are perfectly *ſtraight*; and Thirdly, ſuch as *communicate* with each other, and are *twiſted* together, which reſemble the Branches of Trees.

7. That there are three Sorts of Pores in the Earth.

8. Beſides theſe three Sorts of Pores, there is yet a fourth, which requires particular Attention in order to a clear Underſtanding of them, becauſe of the Conſequences which we ſhall afterwards draw from it. And here it is neceſſary in the firſt Place to recollect what was formerly ſaid concerning that ſubtle Matter, which by entering into the Earth's Vortex at thoſe Places which are near its Poles, and ſo getting from thence the Earth itſelf, cauſes the Earth always to keep its Axis parallel to itſelf, during its annual Motion about the Sun. After this, we muſt obſerve, that though the violent Agitation of the Parts of the Matter of the firſt Element, do generally hinder them from being of any certain Figure; yet the greateſt Part of thoſe which enter into any Vortex, acquire ſome particular Figure which they remain in for a long Time. For Inſtance; becauſe the Matter which enters into the Earth's Vortex, moves very nearly in a ſtraight Line from one of its Poles to the Center, therefore a great many of its Parts are at reſt with regard to each other; which makes them ſtick together, and as I may ſay, congeal, and become of the ſame Figure as the Space is through which they paſs; in the ſame manner as melted Wax grows hard, and takes the Figure of the Mould into which it is caſt. Now becauſe the Matter of the firſt

8. That there is Matter continually deſcending towards the Poles of the Earth, in the Form of a Screw.

Element, takes its Figure by paſſing through the Triangular Space which muſt neceſſarily be left between three Globules of the ſecond Element, therefore the Figure ſo acquired will be that of a long ſlender Body, all along which there will be three Channels, and thoſe very direct, if all the Globules of the ſecond Element were ranged in ſuch order, that the triangular Intervals betwixt them, agreed exactly with each other; But becauſe this cannot be: If on the contrary, we imagine a great many Ranks of theſe Globules to ſurround the Earth; the Interval between three Globules of the uppermoſt Rank, muſt neceſſarily be directly againſt ſome Globule of an inferior Rank. Conſequently the Matter of the firſt Element, muſt deſcend towards the Center of the Vortex, by winding continually round, and will therefore acquire a Figure pretty much like that of a Screw with three [1] Channels in it.

1. That the Channel of the Screw which deſcends towards the Arctick Pole is turned the contrary way to that which deſcends towards the oppoſite Pole.

9. And becauſe the Particles of the ſecond Element which are at a certain Diſtance from the Earth, turn a little faſter from Weſt to Eaſt than thoſe which are in the upper part of the Vortex; this cauſes the Matter of the firſt Element to turn one particular Way, as it deſcends about the Axis of the Vortex; whence it is eaſy to conclude, that the Parts of the Matter of the firſt Element, which deſcend towards one of the Poles of the Earth, acquire the Form of a great many ſimilar Screws, all of them wreathed the ſame Way; and that thoſe which deſcend towards the oppoſite Pole, become of the Shape of the other Screws wreathed the contrary Way.

10. Of a fourth Sort of Pores to be met with in the Earth.

10. Theſe things being ſuppoſed; though we are certain that there are a great many Pores in the Earth which are filled up in Time with the Parts of the third Element which ſwim amongſt thoſe of the firſt and ſecond Element, and whoſe Motion is eaſily ſtopped when they meet with any Obſtacle, becauſe they are of ſuch Figures as are eaſy to be entangled; yet we are not to underſtand this to be ſo in thoſe Pores juſt now deſcribed, through which the Matter ſhaped like a Screw paſſes, becauſe this Matter keeps its Paſſage through theſe Pores always open. All the Conjecture that we can make about theſe Pores is only this, that they contract themſelves ſo as to leave only juſt as muſt Space

1 See *Vitruvius* Book III. Chap 3.

as is neceſſary for the mere Paſſage of the channelled Particles. Whence it follows, that theſe Pores (which are the fourth Sort that we are to examine) are ſo many Receptacles parallel to each other, and that thoſe of them which receive the channelled Matter which comes from the Arctick Pole, are turned the contrary Way to thoſe through which the channelled Matter which deſcends from the Antarctick Pole, paſſes.

CHAP. II.

Of the AIR.

WE generally give the Name of *Air* to all that liquid and tranſparent Matter in which we live, and which ſpreads its ſelf all round the whole Globe compoſed of Earth and Water. Now Air, taken in this Senſe, is indeed a very ſtrange and wonderful Compoſition, not only becauſe of the Matter of the firſt and ſecond Element, a great Quantity of which is to be found in it, but alſo becauſe of the different Bodies which are continually raiſed and exhaled out of the Earth. Wherefore, before we can throughly underſtand the Nature of the Air, we muſt know the Nature of all theſe Bodies. But becauſe we ſhall treat of them afterwards, that we may proceed in a proper Method, we will now conſider by itſelf, what Air properly is, without the Mixture of any other Bodies with it, that is to ſay, what pure ſimple Air is, which the Commentators upon *Ariſtotle* have given the Name of Element to.

1. What is meant by the Word Air.

2. In order hereunto, we need only imagine the Air to be a large Heap conſiſting of an infinite Number of the ſmall Parts of the third Element, which are like Branches, of very irregular Figures, pretty much like thoſe which we before ſaid that the Earth was compoſed of, only ſmaller and looſer; which make them in continual Agitation ſo long as they are ſwiming amongſt the Particles of the firſt and ſecond Element. Wherefore though it ſhould ſeem by their Figures, that they are very apt to lay hold of and entangle each other, yet they cannot really do ſo, becauſe they are ſo very fine, as to give way to the leaſt Impreſſion made upon them by

2. Of the particular Nature of Air.

by the Matter of the firſt and ſecond Element, which eaſily bends them that Way which will diſunite them; and becauſe their Branches are ſo very ſmall and ſhort that they cannot be tied up in Knots.

3. Of the ſeveral Properties of the Air.

3. The Air therefore muſt always be liquid, and can never be hardened, as we ſee Water is when it is frozen; ſo likewiſe, it ought to be light, becauſe there is but a ſmall Quantity of the proper Matter of it in a large Compaſs; it ought alſo to be tranſparent, becauſe, it being in continual Agitation itſelf, it cannot ſlacken the Motion which luminous Bodies impreſs upon the Parts of the ſecond Element in which it ſwims, and by Means of which it tranſmits the Light, and raiſes the Senſation of it. Laſtly, it muſt alſo be very much condenſed, not only when the Heat or Agitation of its Parts being conſiderably leſſened, they are unable to daſh againſt each other, or drive one another with ſo great Violence as uſual; but alſo when they are contained between the Parts of other Bodies which compreſs them more than ordinary. On the other Hand, [1] it muſt be dilated, when the Cauſes of its Confinement are taken away; by heating it, if it was before condenſed by Cold, or by opening the Priſon in which it is contained, if its preſſure only was the Cauſe of its being reduced to a leſs Compaſs.

1 *It muſt be dilated, &c.) How great the Compreſſion or Dilatation is,* ſays the famous Dr. *Wallis, which the Air is capable of, is not eaſy to tell; it is certainly very great, more than any one, who has not try'd, would think, as appears by Experiments.*

Merſennus *ſometime ago, affirms that by the help of an Æolipile, applying a very great Heat, (as much as that Sort of Veſſel would bear without melting) he dilated the Air ſo much as to take above ſeventy times the Space which it did before.*

And our Honourable Mr. Boyle, *without the Aſſiſtance of Heat, found that the Air, by its elaſtick Force only, expanded it ſelf into a Space, firſt nine times greater than before; then thirty one times; after that, ſixty times; and laſt of all, a hundred and fifty times, which is more than double* Merſennus's *Expanſion. After all this, he promoted that Expanſion by other means to above eight thouſand times (by its elaſtick Force without applying any Heat) at which Experiment* (ſays the famous Dr. *Wallis*) *I was preſent. Then by the making uſe of another Experiment ſtill it came to above ten thouſand times, nay to take up thirteen thouſand ſix hundred and ſeventy nine times as much Space as at firſt.* See *Wallis's* Hydroſtat. Prop. 13.

Now this Dilatation was made in Air without its being artificially compreſſed, ſo that it appears, that the Air which we breathe here upon the Superficies of the Earth, is, by its own Weight only, compreſſed into the thirteen thouſand, ſix hundred and ſeventy ninth part of the Space which it would take up in a Vacuum. But if it be compreſſed ſtill more by Art, it will appear (as the famous Mr. *Boyle* experienced) that the Space which Air takes up, when it is moſt of all dilated, is to the Space which the ſame Air poſſeſſes, when it is moſt of all compreſſed, as *five hundred and fifty thouſand* to *one*.

4. It

4. It is not beside the Purpose to observe here, that the Dilatation of Air, which is made in this manner, by removing the Obstacles by which it is compressed, ought to be very quick, because its Particles which before were forcibly bent and so moved, endeavour all together to make themselves straight and to expand themselves as much as they can, and that with a Velocity equal to those of the Second Element, by which they are agitated. And upon this Property of the Air is founded the Invention of little portable Fountains, which throw up the Water to a great Height; and of Guns which being charg'd with Air only, will send forth a leaden Bullet with an incredible Swiftness.

4. How it is capable of a very quick Dilatation.

5. The artificial Fountains are made in this Manner. ABCD is a Vessel of very hard Metal that will not bend, of any Figure you please; there is no Hole left in it but at AD, which is so to be stopped by the Tube EF being soldered to the Vessel, that nothing can enter into the Cavity HL, but through the Tube EF: the Bottom of this Vessel is purposely to be contrived with a little descending Cavity in such a manner, that tho' there be no Hole made in it, nor the Tube EF touch it; yet the Extremity F may go a little lower than that same Bottom. Lastly, there is a little Cock at D, by which the Tube is opened and shut.

5. A Description of an artificial Fountain. Tab. XIV. Fig 3.

Which vast Contraction and Expansion seems unintelligible, by feigning the Particles of Air to be springy and ramous, or rolled up like Hoops, or by any other means than a repulsive Power. Newt. Optic. pag. 371. Now this *repulsive Force* is much greater in Air, than in any other Bodies, because it is with great Difficulty generated, and that from very fixed Bodies, and scarce from such without Fermentation, *those Particles receding from one another; with the greatest Force, and being most difficultly brought together, which upon Contact cohere most strongly.* ibid. pag. 372. (*See also the Notes on* Part I. Chap. XXVII. Art. 15. concerning the Force with which the Particles of Light are emitted.) Now that there is such a *repulsive Force* in Bodies appears from hence, that *Flies walk upon the Water without wetting their Feet; and that the Object Glasses of long Telescopes lie upon one another without touching, and that dry Powders are difficultly made to touch one another, so as to stick together, unless by melting them, or wetting them with Water, which by being exhaled may bring them together, and that two polished Marbles, which by immediate Contact stick together, are difficultly brought so close together as to stick,* ibid.

As to the efficient Cause of this *repulsive Force,* See what is said concerning the Cause of *Attraction, in the Notes on Part* I. Chap. XI. *Art.* 15.

Lastly, It is an Experiment of the *famous Mr. Boyle's* very well worth observing, that Air enclosed several Years in a Glass Vessel, lost nothing of its elastick Force (which he could perceive) though all other Bodies, when forcibly detained in an undue Position, lose their Stiffness by Degrees, and become weak. Whether Air can be generated from some Bodies and converted into others; See *the Notes on the following Chap.*

6. The Use of this Fountain.

6 Now as to the Use of this Fountain, and the Manner of setting it to work: The Tube EF is to be opened, and a Syringe fitted to the Mouth E, by which as much new Air as we can, is to be forced into the Cavity HL, to condense the Air which was there before, and then the Hole E is to be stopped. After this, another Syringe filled with Water, is to be fitted to the same Hole, and to be thrust into the Cavity a little deeper, that the Air which was put into the Vessel do not force it out again, when the Cock is opened; then the Cock is to be opened, and all the Water in the Syringe to be forced into the Vessel; then having turned the Cock, the Syringe must be filled with Water again, and forced into the Vessel as before, and so on, as often as it can be. The Engine being thus prepared; as soon as ever the Cock is unturned, the Air within by endeavouring to dilate it self, presses upon the Water which is at the Bottom of the Vessel, and forces it through the Tube EF with great Violence; so that it is very pleasant to see it rise up into the Air, and play like a Fountain.

7. A Description of a Wind Gun. Tab. XIV. Fig. 4.

7. We shall now give you the Figure and Description of a Wind-Gun. AA is a Tube of Metal well soldered together; open at one End I, and stopped at the other End; the hollow of this Tube answers to what we commonly call the Barrel of a Gun. BB is another Tube of Metal, within which the Tube AA is so placed, that Air may be included in the intermediate Space CC. G is a Hole stopped with a Valve which will open inwards, that is, will permit the Air to pass forward from L to C, but not to go back from C to L. The Tube AA has also two other Holes E and D, at that End which resembles the Breech of a common Gun: Through the Hole E, the Air contained in the Space CC could pass into the Barrel of the Gun, but that it is hindred by a Valve which can open only outwards and is pressed so much the harder against the Hole which it stops, by the Air contained in the Space CC, as that Air endeavours to get into the Barrel with more Violence. By the other Hole D there is a Communication betwixt the external Air and all that in the whole Engine. And that the Air which is contained in the Cavity CC may be hindred from getting out there, there is a short Tube placed between D and E, the Extremities of which are soldered to the Holes of the Tubes AA and BB. Lastly, HH represents the Body of a Syringe, by which as much Air as can be

is

is crouded into the Space CC: Which being done, and a leaden Bullet thruſt into the Tube AA as far as O, the Gun is charged. And in order to diſcharge it, we need only put into the Hole D a ſmall round Stick, fitted to it as exactly as poſſible, with which puſhing away the Valve at the Hole E, as ſoon as that Hole is open, the Air contained in the Cavity CC, will dilate itſelf, and ruſhing into the Gun, will drive out the Bullet without making much Noiſe.

8. Of white Powder.

8. The very little Noiſe which theſe Guns make in going off, has given Occaſion I believe, for the Fiction of that white Powder, which goes off without making any Noiſe; a Secret which the firſt Inventers of theſe Guns, who would have them paſs for common Guns, very much boaſted of. But it is evident, that this Powder is only a mere Story; becauſe whatſoever is able to drive a Bullet out of a Gun with the ſame Velocity that Gun-Powder does, muſt likewiſe ſtrike the Air with the ſame Force, and conſequently make as much Noiſe. But though theſe Wind-Guns ſend forth a leaden Bullet with a ſurprizing Switneſs, yet it falls very much ſhort of the Swiftneſs cauſed by Gun-Powder in a common Gun; and therefore it is no wonder that they make leſs Noiſe when they go off.

9. That the Air is heavier in thoſe Places which are near the Poles, than in thoſe that are near the Equator.

9. To what has been ſaid concerning the Nature of the Air, we may add further, that the Air being liquid, it ought to gather it ſelf about the Earth in ſuch a manner, that the external Superficies of it may be ſpherical. But becauſe it is more condenſed by the Cold near the Poles, than it is in other Places, it follows, that there muſt be a larger Quantity of it in thoſe Places, and conſequently it muſt be of a greater Weight than in the Places near the Equator: And this appears to be indeed ſo by Experiments; for the Mercury riſes higher, in the Barometers formerly deſcribed, in *Sweden* and *Denmark*, than in *France* and *Italy*,

10. What Matter is to be found above the Air.

10. Now if we would aſcend up beyond that groſs Air, whoſe Parts we have been now deſcribing, in order to find out what is there; it ſeems to me eaſy to gueſs, that there is nothing elſe there but Matter of the firſt and ſecond Element. For if any other Matter were placed there, it could not continue there long, but would preſently be driven towards the Center of the Vortex, becauſe it cannot be in ſo great Agitation, nor have ſo much Force to go off from that Center, as the ſubtle Matter has; ſo that it can be only this Matter which is

above the Air. As to the Name which this Matter may be call'd by, I agree to that of *Æther*, which is that by which *Aristotle* call'd it; But as to the Word *Fire*, I can by no means agree, that it should be called so; because this Word is used to signify a hot and luminous Substance; and by so calling it, we should give occasion to many to think, that there is a Fire above the Air, like that which warms us and shows us Light here below; but this is contrary to Experience, not only because it shows us no Light in the Night, but also because it is so far from causing any Heat, that on the contrary, the higher we go above the Superficies of the Earth, the colder we find it.

CHAP. III.

Of WATER.

1. Of the Nature of Water.

IN order to a more distinct Knowledge of the Nature of terrestrial Things, let us consider the Earth again. And here it is to be observed, that the Earth being (as we said before) porous, and there being a Plenum in Nature, its Pores must necessarily be filled with the Matter of the first Element. But because these Pores are long and very straight, their Length and extreme Smallness will not permit the different Parts of this Matter to move otherwise than along them only: This makes them to be as it were at rest with respect to each other, and to stick together, and form very small Bodies of the same Shape as these Pores. Now if we examine what (amongst all the Things in Nature) a Mass, consisting of an infinite Number of these small Bodies, which were formed in those *undulating* Pores, like so many Moulds, and which consequently resemble small Threads, which must be very pliable, because during the Formation of them, they were several Times bent different Ways, may be compared to; we shall have reason to think that it exactly resembles what we call Water, and is of the same Nature; because we shall find in it all the Properties which we observe to be in Water.

2. For

2. For firſt, if Water reſembles a Collection of ſuch ſmall Bodies, it is certain, that it ought to be liquid; becauſe the Parts of it being very ſlender, they are eaſily put in Motion by the Particles of the ſecond Element, which enter in between them and ſurround them on all Sides. But there is no Inconſiſtency in ſuppoſing that it may ſometimes become hard, and appear in the Form of Ice; becauſe at ſome Times, and in ſome Places, the Matter of the ſecond Element, being much leſs agitated, or much more ſubtle than ordinary, may conſequently not have Force enough to move the Parts diſtinctly amongſt each other, to that Degree as to make them liquid.

2. Why it is generally liquid, and how it may be congealed

3. The Heavineſs of Water is alſo a natural Conſequence of this Suppoſition; becauſe Weight depends ſolely upon this, that the Parts have not ſo great Motion as is requiſite to cauſe them to go off from the Center of the Earth; wherefore they muſt neceſſarily be impelled that Way by the Action of the ſecond Element; And this is the Reaſon why Water is heavy.

3. Why it is heavy.

4. Now we have no Reaſon to wonder, that Water when it is hardened into Ice, is cold; for this is a natural Conſequence and Effect reſulting from the Parts being at reſt, as was before explained when we treated of *Cold*: But when it is liquid, Heat or Cold are equally indifferent to it; becauſe by the Nature of it, it is equally ſuſceptible of greater or leſs Agitation, which is neceſſary to make it hot or cold.

4. That Cold is not more natural to Water than Heat.

5. And though Water which is heated upon the Fire, grows cool by Degrees, it is not becauſe it has any particular Diſpoſition to being cold; but proceeds from hence, that it communicates at ſuch a Time ſome of its Motion (in which its Heat conſiſts) to the Things which ſurround it, and which are leſs agitated than it ſelf: And this is confirmed from hence, that if we put hot Water into ſuch a ſort of a Veſſel as will any way hinder it from having ſo much Communication with the Things about it, whoſe Parts are ſuſceptible of Motion; we find by Experience, that it will preſerve its Heat a long while.

5. That cold Water has no Tendency of it ſelf to freeze.

6. When Water is pretty much heated, ſome of its Particles will get out of their Places and fly up into the Air, where they are turned round by the Matter of the firſt and ſecond Element which they are mixed with, and made to unfold themſelves to their full Length, and to drive every Way round them, all the Particles of the Air

6. That Water is capable of being very much rarified.

which they meet with in thofe Spherical Spaces of which themfelves are, as it were, the Diameters.

7. That the Particles of Water do not alter their Nature by being evaporated.

7. This great Agitation of the Parts of Water which caufes them to feparate from each other, is [1] all the Alteration that Water undergoes, when we fay that it is converted into Vapours; as is proved from hence, that if they lofe any of their Motion, as they really do when they meet with cold Bodies, we fee that they unite themfelves together again, and compofe the fame fort of Water which they did before they were converted into Vapours.

8. That Air cannot be converted into Water.

8. I know there are fome who are prejudiced with this Opinion, that Water which is evaporated, turns into Air; and who alfo believe, that Air changes its Nature and is converted into Water, when we fee the Surface of a cold Body, expofed to the Vapours excited in the Air, covered over with Water: But in order to undeceive fuch Perfons, I will tell them an Experiment, which I have made, and which they may make themfelves, it being very eafy to be done, which will fhow them that Air cannot be changed into Water. I took one of the Glafs-Bottles with a long Neck, which the Chymifts call *a Bolt-Head*, which held about 2 Gallons, and fealed it hermetically, fo that it might continue full of Air: After that, I put it into a Tub that was filled with Water,

1. *All the Alteration that Water undergoes, &c.)* Water feems not capable of being converted into Air, becaufe its Parts are not ftiff and fpringy, but will eafily bend and turn round. Yet the famous Mr. *Boyle* obferved, that Water, by being often diftill'd, might generally be converted into an earthly Subftance; and we know that in the Courfe of Nature, Water, or fome Subftance contained in Water, is every Year converted into Herbs, Corn and Wood. So likewife Air is not changed into Water by Compreffion; yet Air feems to be generated out of a great many Bodies. For amongft other Experiments made in Vacuo, the famous Mr. *Boyle* obferved, that a Subftance very like Air, and which had all the Effects of the Elafticity of Air, was generated from Iron and Oyl of *Vitriol*, from Bread, Grapes, new Wine, boyled Apples, from a great many Sorts of Fruits, from Beans, Flefh, Herbs, Flowers, and a great many other Bodies. But upon examining the Thing more clofely, this was fo far from being pure Air, that Animals fhut up in this Subftance, could not only not breathe in it without being hurt, but they died in it much fooner than in a Space entirely empty. So that it is neceffary, that this fhould be mixed with the open Air, generated from all other Sorts of Bodies, before it be fit for Refpiration.

Water, and ſtood in the Cellar, where it remained for three whole Years without Interruption, except that I now and then took it out to ſee what was contained in it; but I could never perceive the leaſt ſenſible Alteration to be made in the Air, nor that there was the leaſt Drop of Water made. Which there would doubtleſs have been, by Reaſon of the Cold which ſurrounded the Bottle, if there really were any ſuch Tranſmutation of Elements as ſome Philoſophers imagine.

9. Why Vapours riſe up to a great height.

9. The Reaſon why Vapours are ſeparated and riſe up (as we ſee them) into the Air, is becauſe they daſh againſt each other from all Sides, and drive one another all Ways, ſo that they have not Room enough to extend themſelves ſo much, as the Agitation they are in requires, unleſs they recede from the Earth, and riſe up into the Air, where generally they meet with leſs Reſiſtance from that Part of the Air which is above them, than from the Bodies which are beneath or on the Sides of them.

10. Why Water has ſcarce any Taſte, and no Smell at all.

10. Becauſe the Parts of Water are very eaſily bent, therefore they cannot put the Bodies againſt which they ſtrike into any great Agitation, any more than a Body can be put in Motion, by darting a Piece of Thread directly againſt it; whereas it might be very ſenſibly moved by ſtriking upon it with a Stick of the ſame Length, Thickneſs and Weight. And this is the Reaſon why Water when we drink it, ſlides along the Tongue and ſo is inſipid, and unable to excite almoſt any Senſation of Taſte. And becauſe in Bodies that Smell, thoſe Parts which excite the Senſation of ſmelling in us, are the ſame which excite the Senſation of Taſte when they are applied to the Tongue; it is manifeſt, that Water, which cannot excite the Senſation of Taſte, cannot for the ſame Reaſon have any Smell.

11. Why Water enters ſo eaſily into the Pores of a great many hard Bodies.

11. Their being thus eaſy to bend, is alſo the Reaſon why the Parts of Water can enter into the Pores of hard Bodies, though they be not exactly Straight, and can alſo get out of them again afterwards.

12. Why it cannot paſs through the Pores of ſome Bodies at all.

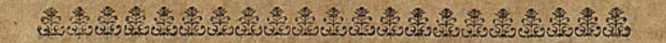
12. But becauſe the Parts of Water, are of a determinate Bigneſs and of a certain Figure; therefore the Pores muſt be of a certain Bigneſs at leaſt for them to enter in. Wherefore, when we ſee Water paſs through ſome Bodies, and is contained in others, which we are aſſured from Reaſon have Pores alſo, it is no more ſurpriſing, than to ſee ſome Grain paſs through a Sieve where the

Holes are large, and not paſs through another where the Holes are ſmall.

13. A Miſtake of the greateſt part of Philoſophers about the Nature of Water.

13. This Conſideration, namely, that Water can eaſily paſs through ſome Pores, and not at all through others, may ſerve to undeceive thoſe who think that Water is one continued homogeneous Body, without any real Diviſion, and that it is therefore liquid becauſe it is capable of being divided all Ways and in any Manner. For if this were ſo, there could be no mathematical Point aſſigned in Water, but that the Water could as eaſily be divided in that Point as in any other; that is, it could very eaſily be divided indefinitely. Conſequently Water might as eaſily paſs through the Pores of Glaſs, as through thoſe made by Grains of Sand when they touch one another; which is manifeſtly contrary to Experience.

I might here deduce many other Properties of Water as Conſequences of that Nature which we have aſcribed to it, but, it will be more convenient to ſpeak of theſe in other Places; wherefore I ſhall now go on to explain the Nature of Salt.



CHAP. IV.

Of SALT.

1. Of the Nature of Salt.

MY Deſign here is to treat principally of common Salt, ſuch as is made out of Sea-Water: And in order to our underſtanding the Nature of it, and finding out all its Properties, we need no more than to imagine it to be a Maſs made up of a great Number of ſmall, long and ſtraight Parts, every one of which is compoſed of the Matter of the firſt Element, congealed and put into ſuch Form by paſſing through the long ſtraight Pores, which we know are chiefly to be met with in the inward Parts of the Earth. This being ſuppoſed, it will explain all the Properties of Salt.

2. Why Salt is hard.

2. And firſt; becauſe the Matter of the firſt Element is not forced to bend it ſelf different Ways, nor to be ſo much diſunited, in concreting itſelf, in thoſe Pores which are perfectly ſtraight, as in thoſe which are crooked

ed and undulating; therefore there muſt be more Matter at Reſt, to compoſe a Particle of Salt, than to compoſe a Particle of Water, and conſequently the Parts of Salt muſt be more ſolid, and harder to bend than the Parts of Water. Wherefore ſince the Parts of Water do ſometimes reſiſt the Force of the ſecond Element ſo much, as to continue at reſt, with reſpect to each other, and ſo compoſe a hard Body; this Property ought with ſtill greater Reaſon, to be found in the Parts of Salt.

3. Why it is heavier than Water.

3. The ſame Argument which proves Salt to be hard, does alſo prove that every one of its Parts is heavier than thoſe which compoſe Water; It is alſo certain, that larger Pieces of Salt, ought to be heavier than an equal Quantity of Water; becauſe the Parts of which theſe Pieces are compoſed, are of ſuch a Figure as will permit them to be more cloſely united together, ſo as to contain more terreſtrial Matter, than there is in equal Quantities of Water. It is therefore no wonder that Salt ſinks to the Bottom in Water. But if it be diſſolved, that is, divided into its component Particles; we ſee that it ſwims in the Water, and does not precipitate to the Bottom; which Effect ought not to be aſcribed to the Smallneſs of its Parts, but to the Nature of the Liquid Body in which it ſwims; which is of ſuch a Sort, that its Parts, by eaſily mixing with, and entangling the Parts of the Salt, and moving all Ways indifferently, bring them up along with them, in great Numbers, as readily as they fall down. [1]

4. Pure

1. The Nature and Properties of Salt are more clearly and fully explained by the incomparable Sir *Iſaac Newton* in the following Manner. 'When *Mercury* ſublimate, is reſublimed with freſh Mercury, and becomes *Mercurius dulcis*, which is a white taſteleſs Earth ſcarce diſſolvable in Water, and *Mercurius dulcis* reſublimed with Spirit of Salt, returns into *Mercury* ſublimate; and when Metals corroded with a little Acid turn into Ruſt, which is an Earth taſteleſs and indiſſolvable in Water, and this Earth imbibed with more Acid becomes a metallick Salt; and when ſome Stones, as Spar of Lead, diſſolved in proper *Menſtruums* become Salts; do not theſe things ſhew that Salts are dry Earth and watry Acid united by Attraction, and that the Earth will not become a Salt without ſo muſt Acid as makes it diſſolvable in Water? -------- As Gravity makes the Sea flow round the denſer and weightier Parts of the Globe of the Earth, ſo the Attraction may make the watry Acid flow round the denſer and compacter Particles of Earth for compoſing the Particles of Salt. For otherwiſe the Acid would not do the Office of a Medium between the Earth and common Water, for making Salts diſſolvable in the Water; nor would Salt of *Tartar* readily draw off the Acid from diſſolved Metals, nor Metals the Acid from *Mercury*,

4. Why Salt melts when exposed to the Air.

4. Pure Air is composed of Particles too fine to agitate the Parts of Salt against which they strike, they are rather reflected back again with their whole Motion. Wherefore when we see Salt melt in the Air, we ought rather to ascribe it to the Parts of Water which fly about in the Air in the Form of Vapour, than to the Parts of Air themselves; for we observe that the Weather is always moist when the Salts melts.

5. Whence arises its Taste.

5. The Particles of Salt can easier move with their Points forward, than obliquely, because they are long and straight: And because they are inflexible also, they have the more Force to shake the small Capillaments of the Nerves of the Tongue, and thereby excite the Sensation of a sharp Taste.

6. This

' *Mercury*. Now as in the great ' Globe of the Earth and Sea, the ' densest Bodies by their Gravity sink ' down in Water, and always endeavour to go towards the Center ' of the Globe; so in Particles of ' Salt, the densest Matter may always ' endeavour to approach the Center ' of the Particle. So that a Particle ' of Salt may be compared to a ' *Chaos*, being dense, hard, dry and ' earthy in the Center; and rare, ' soft, moist and watry in the Circumference. And hence it seems ' to be, that Salts are of a lasting ' Nature, being scarce destroyed, unless by drawing away their watry ' Parts by Violence, or by letting them ' soak into the Pores of the central ' Earth, by a gentle Heat in Putrefaction, until the Earth be dissolved ' by the Water, and separated into ' smaller Particles, which by Reason ' of their Smallness, make the rotten ' Compound appear of a black Colour.

' If a very small Quantity of any ' Salt or Vitriol be dissolved in a great ' Quantity of Water, the Particles of ' the Salt or Vitriol will not sink to ' the Bottom, though they be heavier in Specie than the Water, but ' will evenly diffuse themselves into ' all the Water, so as to make it ' as saline at the Top as at the Bottom. And does not this imply ' that the Parts of the Salt or Vitriol ' recede from one another, and endeavour to expand themseles, and ' get as far asunder as the Quantity ' of Water in which they float will ' allow? And does not this Endeavour imply that they have a repulsive Force by which they fly from ' one another, or at least, that they attract the Water more strongly than ' they do one another? For as all ' things ascend in Water which are ' less attracted than Water, by the ' gravitating Power of the Earth; ' so all the Particles of the Salt which ' float in Water, and are less attracted ' than Water by any one Particle of ' Salt, must recede from that Particle, and give way to the more attracted Water.

' When any saline Liquor is evaporated to a Cuticle and let cool, ' the Salt concretes in regular Figures; which argues, that the Particles of the Salt before they concreted, floated in the Liquor at equal Distances in rank and file, and ' by Consequence that they acted upon one another by some Power ' which at equal Distances is equal, ' at unequal Distances unequal. For ' by such a Power they will range ' themselves uniformly, and without ' it they will float irregularly, and ' come together as irregularly. *News. Opt. pag.* 362.

6. This Figure added to their Stiffneſs, makes them capable of entring into the Pores of Fleſh-meat, and hindering it from being corrupted; for they get into the Place of an equal Quantity of finer Matter which they drive out, the Agitation of which might have cauſed the other Parts to have ſeparated from each other. Further, by ſticking amongſt the Parts of the Fleſh like ſo many ſtrong ſtiff Wedges, they hinder the more flexible Parts which are amongſt them, from being agitated and diſturbed; and this is the Reaſon why they keep Fleſh from corrupting, and why in length of Time it grows hard.

6. Wherein conſiſts its Vertue to keep and harden Fleſh.

7. When Salt is diſſolved in Water, the Parts of the Water have an Opportunity of moving round about the Salt, and being always bent in the ſame manner, they can very commodiouſly paſs out of one Part into another; whereas, when the Parts of Water are not mixed with thoſe of Salt, they are forced to bend and unbend themſelve continually all Sorts of Ways, which takes off ſome of the Force, which the Matter of the ſecond Element agitates them with; ſo that there remains leſs Force to move the Parts of Water alone, than to move them when they are mixed with thoſe of Salt; whence it follows, that freſh Water is more apt to loſe its Motion, or to be turned into Ice than ſalt Water.

7. Why ſalt Water is harder to freeze than freſh Water.

8. If we conſider that the Reaſon why Water is tranſparent, is, becauſe the Matter of the ſecond Element, which is in the Pores of it, tranſmits the Action of luminous Bodies through it, we ſhall have Reaſon to conclude, that Salt-Water ought to be more tranſparent than freſh Water, becauſe the Matter of the ſecond Element which is in the Pores of Salt-Water, keeps it ſelf in greater Motion than that which is in the Pores of freſh Water, and conſequently is more capable of tranſmitting the Action of luminous Bodies.

8. Why it is more tranſparent.

9. It is generally looked upon as a ſurprizing Thing to ſee, that if in a warm Place, pretty nearly an equal Quantity of Salt and Snow or beaten Ice be mixed together, and laid round about a Glaſs full of Water, the Water in the Glaſs will freeze in Proportion as the Salt and Snow melt: But we ſhall eaſily comprehend the Reaſon of this, and ſo ceaſe to wonder, if we conſider; that in what manner ſoever the Water be frozen, whether it appears in the Form of Ice or in the Form of Snow; the Matter of the ſecond Element which is in the Pores of it, muſt be more ſubtle or leſs agitated, than that

9. A ſecret to freeze Water in a warm Place.

that which is in the Pores of common Water (otherwiſe the Ice or Snow would continue liquid ſtill.) On the contrary, if the Air be temperate, (as we now ſuppoſe it to be) the Matter of the ſecond Element, which is in the Pores of the Air and of the Water contained in the Glaſs, muſt be leſs ſubtle and more agitated, than that which is in the Pores of the Snow or Ice: Now becauſe the ſubtle Matter which is in the Glaſs, has a continual Tendency to paſs from one Place to another, and chiefly to a Place where it can move itſelf with greater Freedom; it follows, that it muſt really paſs into the Pores of the Salt and Snow which are melting, where it can eaſier move than in the Pores of the Water contained in the Glaſs; and at the ſame time, an equal Quantity of more ſubtle and leſs agitated Matter which before was in the Snow or Ice, muſt enter into the Glaſs, in order to ſucceed and take the Place of that which is gone out of it; which not having Force ſufficient to put the Parts of the freſh Water which is in the Glaſs into Motion, it cannot prevent their own Gravity from ſtopping them one againſt another, nor conſequently from becoming a hard Body, that is, [1] they muſt freeze.

10. Why Salt will not evaporate.

10. The Chymiſts ſay, that Salt is a very fixed Body, becauſe they find by Experiments, that it is with great Difficulty that it is made to evaporate; the Reaſon of which may be collected from that Nature which we have aſcribed to it: For beſides that it is heavier than Water, it is certain, that it muſt be very difficult for it to riſe up by turning round as the Parts of Water do when they aſcend in Vapours; becauſe the Stiffneſs of the Parts of Salt, when they daſh one againſt another, are a Hindrance to this Sort of Motion. So that they can hardly aſcend at all, except it be with their Points upwards; now becauſe in this Poſition, every Part has one End turned towards the Earth, their own Weight muſt make them deſcend with greater Force, than the little ſubtle Matter which is applied to the Points of them, can make them aſcend.

11. When

1. *They muſt freeze, &c.*) The Experiment will ſucceed as well, if inſtead of common Salt, you make uſe of Nitre, diſtill'd Liquors, Sugar, or any ſuch like Bodies; but *Sal Ammoniack* is by far the Beſt of all. See *the Experiments of the Acad.* del Cimento, *pag.* 100. *and the Notes on Part* I. *Chap.* 23. *Art.* 48 *and* 54.

11. When the Parts of Salt then are ſeparated from thoſe of the Water, it muſt be a very extraordinary Force, ſuch as we find by Experience there is in Flames, that can keep them in Motion, and make it appear to us in the Form of a Liquor; now if the Salt be added to that Matter which uſes to nouriſh Flame, the Solidity of the Salt will make that Matter ſtill more powerful, and capable of diſſolving Bodies which can commonly bear the Fire, ſuch as the greateſt part of Metals are: And this is the Reaſon why Workmen make uſe of Salt to help the Fire to diſſolve Metals.

11. How it is of uſe to melt Metals.

12. Becauſe the Parts of Salt are not limber and eaſy to be bent like thoſe of Water, it is eaſy to apprehend, that if a Mixture of them endeavour to enter into very ſlender crooked Pores, the Particles of Water only will be able to enter in, and thoſe of the Salt will be detained and ſtick in the bending Paſſages: And thus we ſee that Sea-Water in paſſing through a good deal of Sand, will loſe its Saltneſs gradually, and become quite freſh at laſt.

12. Why Salt will hardly enter into the Pores of ſome Bodies.

13. The ſame Stiffneſs which hinders the Parts of Salt from penetrating very far into the winding narrow Pores of ſome Bodies, is alſo the Reaſon why, when they are once entangled in them, it is with great Difficulty that they can get out: Chymiſts therefore are forced to reduce Plants to Aſhes before they can draw out the Salt, by that Means opening the little Priſons where each Particle is detained.

13. Why it is difficult to get out of the Pores it is once engaged in.

14. Salt then being of ſuch a Nature as we have deſcribed, it is not at all ſtrange that when the Waters of the Sea are violently agitated in a very hot Seaſon, its Waves ſhould [1] throw out an infinite Number of Sparks in the Night into the Air. For we ought to conſider, that theſe Waves muſt diſperſe a great many Drops about in the Air, which divide themſelves into ſtill ſmaller Drops; and that ſome of the Particles of the Salt, which are the moſt ſolid and moſt agitated, may then diſengage them-

14. Why the Water of the Sea ſhines when it is in violent Agitation.

1. *Throw out infinite Number of Sparks, &c.*) The following Query of Sir *Iſaac Newton*'s is very well worth conſidering in this Place. *Do not*, ſays he, *all fixed Bodies when heated beyond a certain Degree emit Light and ſhine? and is not this Emiſſion performed by the vibrating Motions of their Parts? And do not all Bodies which abound with terreſtrial Parts, and eſpecially with ſulphureous ones, emit Light, as often as thoſe Parts are ſufficiently agitated, whether that Agitation be made by Heat, or by Friction, or Percuſſion, or Putrefaction, or by any vital Motion, or any other Cauſe? As for inſtance; Sea-Water in a raging Storm, &c.* Opt. page 314.

themſelves from the Parts of the Water, and dart themſelves into the Air with their Points forward, in ſuch a manner as to be ſurrounded only by the Matter of the firſt Element, which may communicate a Force to them ſufficient to impell the ſecond Element, and ſo produce Light.

15. Why ſtagnating Water does not ſparkle at all.

15. However, in order to produce this Effect, it is neceſſary that the Parts of the Salt ſhould be very ſmooth and ſlippery; wherefore Sea-Water which has been kept a long time, and Brine whoſe Parts are covered with Dirt and as it were ruſty, are no Ways proper to produce theſe Sparks.

16. Why this Shining is chiefly ſeen in Summer.

16. It is further neceſſary, that the Parts of freſh Water, which are rolled about the Particles of Salt, ſhould be extremely pliable, ſo as to be able to unfold themſelves very eaſily, and give the Particles of Salt liberty to diſengage themſelves; now this can never be but only in the greateſt Heat of the Summer; and therefore we ordinarily ſee ſuch Sparks in that Seaſon only.

17. Whence it is that all Sorts of Waves are not proper to produce theſe Sparks.

17. Laſtly, it is evident, that in order to this, the Agitation muſt be very violent, and the Parts of the Salt muſt move with their Points forward, that they may the more eaſily diſengage themſelves from the Drops of Water; and this is the Reaſon why the Sparks do not come from all the Waves nor from every Drop of the ſame Wave.

18. How Salt is made in the Salt-Pits.

18. If this Phænomenon have appeared ſurpriſing to a great many, the Conſideration of the Formation of Salt on the Coaſt of *France*, will appear no leſs wonderful. They who make Salt, chuſe ſome very low Place to do it in, which the Sea would overflow when it is high Water, if it were not kept out by a Bank. When the Water in the Sea is very high, they open Sluices by which they let the Salt Water into their Pans or Ponds, which they fill, and then ſhut up the Sluices. This Water is kept ſome Time in the Pans, that Part of it may evaporate and that which remains become ſalter; then they let go this Water into little Channels like the narrow Walks in our Gardens, the Bottom of which is done with Clay, that the Water may not ſink into it. All this is done in the Summer, that the freſh Water may evaporate inceſſantly; and as it evaporates, the Grains of Salt form themſelves upon the Top of that Water which remains in the Channels. Theſe Grains are all of the ſame Figure, which is pretty nearly cubical, except that the upper Square is a little bigger than the Bottom one, and the four Sides tending

tending to Trapeziums a little convex; the upper Square being for the most part a little concave in the Middle. When the first Grains are formed entirely and come to a certain Bigness, they sink down to the Bottom, and then new ones are formed and so on till all the Water is gone; and then the Salt is heaped up, and more made in the same manner.

19. How the Parts of the Salt disengage themselves from the Parts of the Water.

19. In order to explain what is most remarkable in this Account, we must consider, that though the Salt does not ascend up in Vapours, yet it cannot be denied but that some of its Parts are dragged up by the Parts of the fresh Water which the Heat makes to fly up into the Air, so as to rise about two Fingers Breadth along with them into the Air; after which, being loosened from the Parts of the fresh Water which quit themselves and fly from them, they fall down by their own Weight. And that this is so, is very evident from hence, that if some Rods be placed at this Height over the Salt-Water which is evaporating, the Salt will gather round them like Ice, which it will not do if the Rods be placed a little higher. These small Particles of Salt which fall back thus upon the Water, swim upon its Surface, for the same Reason that we formerly said small Steel Needles swam in like Manner. So that they do not sink into the Water at all, but only bend its Surface a little in, and make a small Cavity, at the Bottom of which they remain surrounded with a little Ditch; and whilst there is but a few of them upon the Surface of the Water they disperse themselves to a good Distance from each other, without any order, as they are represented in A.

Tab. XIV. Fig. 5.

20. How they place themselves by the Side of each other upon the Surface of the Water.

20. But when there comes to be a great Number of them, those that fall upon the Surface of the Water afterwards, must necessarily fall upon the Sides of those little Ditches which were made by them that fell first, and so slip down do the Bottom of these Ditches and place themselves by the Sides of the first Particles, as you see them represented in B; in the same manner as small Steel Needles will do when they swim upon the Water; for as soon as any two of them, come pretty near one another, they immediately place themselves by each other's Side.

Tab. XIV. Fig. 5.

21. Why they form themselves into a Sort of a Cross.

21. The Particles of the Salt ought to continue to range themselves in this manner, till there is a sufficient Quantity of them to compose a little Square; but when this Square is formed, then the Hollow made in the Superficies of the Water being every where of an equal Depth, there

Tab. XIV. Fig. 5.

there is no Reason why the new Parts of Salt, should place themselves at the Sides rather than at the Ends of the old ones ; so that they will really range themselves at both the Sides and at the Ends, and so form themselves into a sort of a Cross, as you see represented at C.

22. How the Angles of this Cross are filled. Tab. XIV. Fig. 5.

22. Further, because the Cavity which is now made by these last Particles of Salt, is a little deeper where the four Angles enter into the Cross, than any where else, because these Places are somewhat nearer the Middle than the rest ; therefore if there come any new Particles they must slip into these Places, and dispose themselves as they are represented at D.

23. How a Grain of Salt grows thicker.

23. After a great Number of Particles are united together in this manner, their Weight then becomes sufficient to make the Hollow of the Water pretty deep, and the Declivity of its Sides very sensible. The Particles therefore which fall afterwards, must tumble upon the Particles of the lower Order, and range themselves upon them, in the same manner as they ranged themselves at first. And by thus ranging themselves one upon another, they will become of the Thickness of a Grain of Salt, the Breadth of which will be larger as it grows thicker, because the superiour Order is always composed of a greater Number of Particles than the inferiour Order.

24. How it becomes Square.

24. However, we are not to think that a Grain can become of any sensible Bigness, till a great Number of these Orders of Particles like Leaves, are laid one upon another; and then, because the Length of the Sides of each Leaf is very much increased, a great many of these Particles place themselves at the End of each other, and so join themselves to the first. And because those Places of the Cavity which each Grain of Salt makes upon the Surface of the Water, are deeper the nearer they are to the Middle, and because the Particles of Salt always descend as low as they can ; it follows, that a great many more of these Particles will place themselves in the Place E than in the Place F of the Sides of the foregoing Leaves ; and this will cause the Leaves thus formed to be perfectly Square.

Tab. XIV. Fig. 5.

25. Why the Top of each Grain is hollow.

25. And because the Leaves become at last of a sensible Breadth, and their Superficies so rough and unequal as not to permit the Particles of Salt, which fall afterwards to roll upon them without great Difficulty ; therefore those Particles which compose the last Leaves, which are upon the Top of the Grain, cannot get to the middle, which

which is for that Reaſon hollow in every Leaf; and that makes the Top of each Grain hollow, and cauſes them alſo to ſwim ſo much the longer Time and the more eaſily upon the Water; And becauſe they will not ſink ſo ſoon by their own Weight as they would do if there were no Cavity in them, there is the more Opportunity for new Particles to join themſelves to the old ones, and ſo conſiderably to increaſe the Bigneſs of the Grains.

26. How theſe Grains may poſſibly be very ſmall.

26. At laſt the Weight of the Grain becomes ſo great as to make it ſink to the Bottom of the Water, which happens ſo much the ſooner as the Heat is greater; becauſe the Agitation of the Parts of the Water, makes it the eaſier to give way. And this Heat may be ſo great, that the Bigneſs of the Grains may be ſcarce ſenſible, when they ſink to the Bottom of the Water, ſo that the Salt taken from thence may be like Powder or beaten Salt.

27. Why Grains of Salt may eaſier be broken at the Corners than elſewhere.

27. From the Manner in which we have ſaid that Grains of Salt are formed, we may collect, that they ought to be more brittle at the Corners than any where elſe, becauſe the Parts of the Salt are not ſo regularly ranged at theſe Corners; and hence it is alſo that they are very blunt.

28. Why Salt crackles when it is thrown into the Fire.

28. Further, it is eaſy to conceive that ſome Parts of the freſh Water may be entangled amongſt the Particles of Salt of which the Grains are compounded, and ſo ſtreightned that they cannot be turned round without being folded up. And if an extraordinary Heat ſhould at any Time give them a ſufficient Force to unfold themſelves, they muſt do it by breaking their little Priſon with a Noiſe; which is the Reaſon why Grains of Salt crackle when they are thrown into the Fire. And this is confirmed from hence; that if theſe Grains be very dry, that is, have no Particles of Water amongſt them; or if they be bruiſed and reduced to a very fine Powder, they will then make no Noiſe, or they will loſe the Property of crackling.

29. Why it eaſily melts in the Fire.

29. The Particles of Water which are commonly contained amongſt thoſe of Salt, help to make it melt the more eaſily when it is put into the Middle of a great Fire in a Crucible. So we ſee that the Salt called by the Chymiſts, *decrepitated Salt*, which has loſt all the Water contained in it, is very difficult to melt.

30. That Salt ought to be white and transparent, and without any Smell, and whence that grey Colour and Violet Smell, which it sometimes has, arises.

30. Because the Parts of the Salt are so solid as to resist the Action of the second Element; it follows, that the small Globules of it, (by Means of which, we before said, the Action of luminous Bodies was extended to so great a Distance) must pass quite through, or else be reflected, without any Diminution of their Motion; the Grains therefore must appear either transparent or white. And because these Parts are also very fixed, it follows likewise, that they must be very difficult to be exhaled; so that Salt ought not to have any Smell. If the contrary to this be found by Experience, in that most Salt is Grey, and that Salt when it is fresh made, smells sometimes like a Violet; this does not diminish the Force of our Reasoning; because this Colour and Smell arise from the Mixture and Disposition of foreign Particles which get in and go along with the first Particles of the Salt as the Grains are forming.

31. That pure Salt is not grey, nor has it any Smell.

31. And Experience fully shows this to be so. For if grey Salt be melted in fresh Water and strained, and then laid in the open Air when it is warm and clear, that the Grains may be new formed again; they will lose both the Colour and the Smell which they had before.

32. Concerning some other Properties of Salt.

32. The foreign Particles which mix themselves with the Particles of Salt, being different upon the different Coasts where Salt is made, is the Cause of the peculiar Properties which we find to be in the Salts of different Coasts. And therefore it is no Wonder that the Salt made upon the Coasts of *France* may be of use for some Purposes, which that made upon the Coast of *Spain* is not at all proper for.

33. Why Salt is principally to be found in the Sea.

33. Lastly, It is in the Sea that Salt ought chiefly to be found; For though there is a great Deal of it formed in the Bowels of the Earth, and also in Places that are at a great Distance from the Sea; yet because its own Weight makes it always tend towards the Bottom, and it is many Times carried down by that Means; after it is sunk, the Veins of Water which discharge themselves into the Sea, loosen it and carry it along with them.

34. A Mistake of Aristotle's *concerning the Saltness of the Sea.*

34. I shall only just mention in this Place, that it was a great Mistake in *Aristotle* to assert, that the Saltness of the Sea depends upon its Waters being heated by the Rays of the Sun, for we do not find by Experience, that the Heat or the Sun or even that of Flame, will convert fresh Water into Salt Water.

35. That

35. That which ſeems in ſome Meaſure to favour this Miſtake, is, that roaſt Meat is more ſavory, and taſtes moſt of Salt in thoſe Places which are moſt expoſed to the Fire. And alſo, that the Water in the Ocean is more Salt in the Torrid Zone, where the Sun diffuſes more of its Heat, than in thoſe Places which are near the Poles. As to Meat; it is a known Thing, and allowed by all *Chymiſts*, that there is no Fleſh but has ſome Salt in it, which is pretty equally diffuſed through all its Parts. Now when the Meat is put in Agitation by the Heat of the Fire, ſome of its Particles are driven towards the Superficies, and are alſo exhaled along with the more liquid Parts, which cauſe that Smoke which we ſee riſe out of the Meat when it is roaſting; and becauſe the inſipid Particles only can aſcend to any great Height, or Diſtance; the Particles of Salt can hardly get above two or three Inches from the Meat, before they will deſcend by their own Weight, and fall back upon its Superficies. And this is it that makes thoſe Places taſte ſo quick and ſtrong as we find they do.

35. Why roaſt Meat is moſt ſavory on the outſide.

36. And as to the Difference obſerved between the Saltneſs of the Water of the Sea between the two Tropicks, and that near the Poles; it ariſes from hence, that the Sun's Heat being much greater near the Equinoctial than at thoſe Places which are a good Diſtance from it, a much larger Quantity of freſh Water muſt continually aſcend up in Vapours there than elſewhere, which do not deſcend again in Rain till they are carried a great Diſtance from thence; ſo that there being a leſs Quantity of that which temperates the Salt, to be found in thoſe Seas which are between the two Tropicks, than in thoſe Seas which are in the Frigid and Temperate-Zones; it is no wonder if their Waters are ſalter. To this we may add; that the Ocean is of a much larger Extent between the two Tropicks than any where elſe, and yet there are fewer Rivers diſcharge themſelves into it.

36. Why the Sea is ſalteſt betwixt the two Tropicks.

37. After having thus explained moſt of the Properties of common Salt; there remains nothing more for us to ſay about other Salts which are digged out of the Earth, ſuch as *Nitre*, and *Sal Armoniack*, but only that they are produced much in the ſame Manner, and that whatever is particular in them, is owing to their Parts being more or leſs groſs; and that whereas the Parts of

37. Of the Nature of different Sorts of Salt.

Sea-Salt may be compared to *Cylinders*, [1] the Parts of other Salts may be like *Prisms or Cones*; and lastly, some of these Salts may be so subtle as to fly away by a moderate Heat; as those which the Chymists call *Volatile Salts*.

38. How Oyl or Spirit of Salt is made.

38. There is one Thing very observable, which I must not pass by in Silence, and that is, that all Salts may be so changed as from a hard Body to become liquid. In order to make this Change, they take the Salt and commonly mix Brick-Dust with it, and put them together into an earthen Vessel, which they call a *Retort*; then they set it upon a fierce Fire, by the Force of which the Salt ascends in the Form of a Vapour, and as it condenses, it drops into a Receiver. And this is the Liquor which the Chymists call *Oyl*, or *Spirit of Salt*, or *Aqua-Fortis* which is used to dissolve Metals with.

39. How Salt is converted into a Liquor.

39. In order to know how *Aqua-Fortis* comes by this Force; we must consider, that the Particles of Salt which are very stiff, cannot be made limber, by being forced through the winding Passages which are amongst the Brick-Dust, but at the same Time they must become flatter; and whereas before they resembled little *Cylinders*, they now become like the Leaves of *Reeds*, with sharp Edges on each Side; and herein consists the penetrating Quality of *Aqua-Fortis*, and also its very sharp Taste so much different from that of Salt, which only affects the Nerves of the Tongue when the Points are applied to them, whereas the Parts of *Aqua-Fortis*, cut with their Edges.

40. Of the Nature of Allum and Vitriol.

40. Lastly. All that which is produced by Art in the Laboratories of Chymists, is done naturally in the Bowels of the Earth, where we sometimes meet with sharp and corrosive Juices which are like *Aqua-Fortis*, and which are capable of making infinite Variety of Dissolutions of all Sorts of Bodies, even the hardest of all. Now it is to be observed, that these Juices consist of two Sorts of Particles, the one of which are smaller than the other, and that when the Heat which is within the Earth, has exhaled the finer Parts of these Juices, by which the second Element agitated the grosser ones; the Weight of these latter must cause them to be at rest with respect to

[1] *The Parts of other Salts, &c.*) The Particles of *Nitre*, when looked upon through a Microscope, appear to be Sexangular, thin and long, their Sides Parallelograms, and growing less like a Pyramid one way; from whence the principal Properties of it may easily be deduced. See *Clerc's Physicks*, Book II, Chap. 5. Sect. 18.

to each other, and by that Means to become hard Bodies, in which we may meet with all the Properties which we see by Experience are in [1] *Allum*, and [2] *Vitriol*.

CHAP. V.

Of Mineral OYL.

1. Of the Nature of Oyl.

WE have seen by the several Properties of Water and Salt, what may be produced by the *crooked* Pores *like Waves*, and also by the *straight* Pores which are in the Bowels of the Earth: It remains now that we examine what may be generated by the third Sort of Pores, which we compared to the Branches of Trees. And since there are found in Mines, certain fat oily Liquors which will not easily run; we cannot but think that these various Liquors, are nothing else but Collections of these branched Particles, composed of the Matter of the first Element assembled and concreted in these occult Pores.

2. Why it is Liquid.

2. These Collections may very well be liquid; for though on the one Hand their Parts seem not much disposed to slip one upon another, as the Particles of Water; yet this is made amends for, by their not being so fitted to approach each other; so that there are very large Intervals between them, which may contain a sufficient Quantity of subtle Matter to put them in continual Agitation.

1. *Allum.*) Later Philosophers have observed, that the Particles of *Allum*, when looked at through a Microscope, appear to be a little more compact, and to have a sexangular Plain on one Side, as its Top, and on the other opposite Side a like sexangular Plain, with two Quadrangular Plains lying between. Whence they collect, that it ought to be astringent, to harden and corrode; but because the Ends of the angular Points are somewhat blunt, therefore it is not so sharp as *Vitriol*.

2. *Vitriol.*) Concerning the several kinds of *Vitriol*; the manner of preparing the Medicines, *&c.* See *Pliny*, *Book* 34. *Chap.* 12. Later Philosophers have observed, that its Parts are sharp on both Sides, and consists of ten plain Sides, *viz.* of four pantagonal Plains in the Middle, and three triangular Plains at each End. Whence they collect, that it ought to have a very strong corrosive and astringent Power, and to be the most Acid that can be.

3. Why it is lighter than Water.

3. Thus the Interruption which there is amongst the Parts of oily Bodies makes them also to contain less of their own proper Matter in the same compass, than if their Parts could be ranged in a better Order; and therefore they ought generally to be very light.

4. Why it is less transparent.

4. And they can hardly be transparent, because they hinder almost all the Motion of that Matter by Means of which the Objects which are beyond them act upon the Eye.

5. Why it congeals sooner than Water, but is not so hard.

5. And because the Parts of Oyls are of such Figures as will not allow them to slip by one another with ease, as those of Water do; and yet some of them are near upon as gross as those of Water; it may happen, that the Matter of the first and second Element, may not be able to keep the grosser Particles in Motion, though it may have Force enough to keep the other so; For this Reason, these Oyls may congeal sooner than Water, and yet not become so hard; not only because they are rare, but also because the subtle Matter, which incompasses them, is always agitating the Extremities of the little Branches of which every ramous Particle of Oyl consists; and this makes them to have a kind of Softness.

6. Why it is very hard for the Parts of Oyl to be got out of Bodies in which they are.

6. It is evident that it must be very difficult for the Parts of Oyl to get out of the Pores in which they are formed; and that it is a very bad Way to endeavour to disengage them by a violent Heat; for this will rather break in Pieces their Branches, than draw them out, and by that Means change the Form and Nature of them: It is on the contrary, more proper to make use of something which can enter gently into the Bodies in which Oyl is contained, and separate their Parts and widen their Pores, so as to give the branched Particles an Opportunity of coming out of their little Prisons. And this agrees with Experience; for Chymists have no better Method of drawing Oyl out of dry Bodies than to steep them first in a sufficient Quantity of Water, and then to distil the whole through an Alembick.

7. How Water is of use to exhale Oyl, and that the Earth sends forth more Vapours than Exhalations.

7. Now Water is the most useful for this Purpose, because it will easily and with a moderate Heat ascend in the Form of Vapour, by which Means its Parts will carry the Parts of Oyl along with them, which otherwise could not be moved and put in so great Agitation as to fly away in Exhalations, without a much greater Heat than is necessary to make Water evaporate; and further, the Parts of Oyl are sometimes so entangled with each other, that they

they will burn ſooner than exhale alone. And this is an Obſervation worth remarking; becauſe it ſhows us, that Exhalations cannot riſe out of the Bowels of the Earth, but that they muſt be accompanied with a great Quantity of Vapours, but that theſe latter may often riſe alone.

8. How ſome Sorts of Oyls may be changed into a thin Liquor and others into a glutinous Body.

8. The Nature of all Sorts of Oyl being thus ſuppoſed, it is eaſy to foreſee; that if there be any particular Sort of Oyl, whoſe Parts may be broke in Pieces by being continually bent backwards and forwards, then every little Branch will be broke into as many little Pieces as it is made up of; the Figures of which not being ſo convenient to entangle each other as they were before, they muſt neceſſarily compoſe a thinner and finer Liquor. And, on the contrary, if the Parts of any other Sort of Oyl, are very difficult to break, they may at laſt meet together in ſuch a manner, as quite to entangle each other, and conſequently they will compoſe a Body which will not be liquid at all. Thus it may happen, that ſome Oyls which are kept a long Time, may grow thin, and be converted into a Liquor like Water, which is not inflammable as the Oyl was from whence it proceeded; and that other Oyls may condenſe and become a viſcous Body like ſoft Wax.

9. Of the Nature of Mineral Sulphur, and of the ſeveral Sorts of Bitumen.

9. While the Oyls are concreting in the Bowels of the Earth, and after they are concreted, their Pores may be filled with a foreign Matter which is ſtopped in them, as, for Inſtance, that of the ſeveral volatile Salts; and by this Means, the ſubtle Matter of the firſt and ſecond Element being no longer able to enter into theſe Bodies in ſo great a Quantity as before; they will ſo far loſe their Liquidneſs, as not to recover the Agitation of their Parts but by the Help of a conſiderable Heat: Thus their Nature will be altered, and they will become hard, and very heavy Bodies, ſuch as *Mineral Sulphur*, and the ſeveral Sorts of *Bitumen* taken out of the Earth.



CHAP. VI.

Of METALS.

1. Of Metals and Minerals.

ALL Bodies which are taken out of Mines are called *Minerals* in general, and they are commonly distinguish'd into two Sorts. The first Sort are all those that will melt in the Fire. and can be forged upon an Anvil, and these are called *Metals*; the other Sort, are those which have but one of these Properties at most, and they are called by the general Name of *Minerals*.

2. That we know of but seven Metals.

2. The Metals are, *Gold*, *Silver*, *Lead*, *Copper*, *Iron*, and *Tin*, to which we may also add *Quicksilver*, notwithstanding it be generally liquid, and not capable of being forged: For we place it in the Rank of these, because there are several Ways of making it cease to be liquid, as for Example, by exposing it only to the Smoke of melted Lead. It is concerning these Bodies only, that I intend to speak in this Chapter, and shall reserve what I have to say of *Minerals* to the next Chapter.

3. Of the component Parts of Metals.

3. And first, it is to be observed, That though Salt be in its own Nature very fixed, yet this does not at all hinder but that it may be moved with a very great Velocity, not only whilst it remains in the Pores of the Earth, where it is first formed, and where it must have as much Rapidness as the first Element of which it is composed; but also when it passes out of the Pores of the Earth into other Pores which are a little bigger, if no other Matter but that of the first Element be suffered to surround it: For then, when it has lost a great Deal of its Motion, it will acquire it again, for the same Reason, that we see Water does, when it is mixed with Lime, and enters into the Pores of it. What I have now said of the Parts of Salt singly, is to be understood also of the Parts of Salt, Water and oily Substances mixed together. We apprehend therefore, that all these may be moved together, and go along through such very strait Passages, that they have no room to turn either to the Right Hand or to the Left, but only to move directly forward all together; whence it follows, that being at rest with respect to each other, they will form those little hard Bodies which we imagine to be the competent Parts of Metals.

4. It

4. It is to be obferved further, that thefe Sorts of lit-tle hard Bodies, muft generally be formed very deep in the Earth, where the Earth it felf is very folid, and where fuch Sort of Bodies as are neceffary to form them muft confequently be found; rather than towards its Su-perficies, where its Parts are difunited, and at fuch a Diftance from each other, that the Air and a great many other Bodies differently agitated, can get in betwixt them and hinder them from generating any thing that is fixed, as the component Parts of Metals muft be.

4. That they muft be formed in the Bowels of the Earth.

5. Now it is eafy to apprehend, that the Vapours and Exhalations which afcend out of the Bowels of the Earth with fome Rapidity; may fometimes pafs through par-ticular Places, which though they be indeed very ftrait, yet may be wide enough, compared with the fmall Parts of Metals which are brought thither out of thofe Pores in which, as in fo many Moulds, they were formed and lodged. By this Means, thefe fmall Parts are brought up very near to us, and ftopped in the Sand and other Parts of the external Earth, which is within our Reach, and which Mens Curiofity have led them to fearch into; and being lodged there, they compofe thofe Veins of Me-tals which are afterwards refined by Art.

5. How they may be brought to the Superficies of the Earth.

6. When the Parts of Metals are mixed with an ear-thy Powder, there is no doubt but that Fire is very pro-per to fetch them out and to refine the Metal, be-caufe it will eafily difperfe all that which is not metallick; But if the fame Parts ftick in any Matter which is very hard, and whofe Hardnefs they increafe by filling up its Pores; it will be to no Purpofe to make ufe of the Force of Fire in order to difengage thefe Parts; becaufe Fire will not difperfe any Matter which refifts it very much, without corrupting at the fame Time and reducing into Smoke a great many of the metallick Parts. For this Reafon when any valuable Metals, fuch as Gold or Silver, are to be feparated from any terreftrial Matter which is very hard, there muft be fome Artifice made ufe of.

6. That Fire is not always proper to fepa-rate Metals from the ter-reftrial Mat-ter.

7. But whatever the Manner of refining Metals be, the Metal it felf cannot but be very heavy, becaufe the Parts of which it is compofed, being very grofs and folid, that which is compofed of them, muft confequently be very weighty; and for the fame Reafon it muft alfo be fo hard, as not to be made liquid but by Means of a violent Heat.

7. Of the Hardnefs of Metals.

8. Howe-

8. A particular Reason why Quickfilver *is Liquid.*

8. However, it may happen, that the Parts of a Metal may be fo fmooth and fo well polifhed, and alfo [1] of fuch a Figure, that they can touch one another in a very few Places only: In this Cafe, they will compofe a liquid Body; becaufe the Matter of the firft Element, and fome of the fmaller Particles of the fecond Element, will continue to flow amongft them, and fo keep them in fome kind of Motion.

9. Wherein it differs from other Metals.

9. This Obfervation is very well worth remarking; becaufe it explains to us that particular Quality which makes *Quickfilver* to differ from other Metals. And as to the Differences obferved in Metals, we may affirm in general, that they all confift in this; that their component Parts are of different Bignefs, of different Solidity, and of different Figures.

10. That it is not abfolutely impoffible to turn Lead into Gold.

10. It is therefore no Contradiction in the Nature of Things, that by adding to the Parts of fome cheap Metals, fome other Parts of Matter, which may caufe them to be like the Parts of a valuable Metal, fuch a *Tranfmutation* of Metals may be made, as fo many Chymifts have wifhed for, and which fome of that Profeffion have declared that they have found.

11. But that there is no Hope of attaining the Secret.

11. But becaufe we do not know particularly what the Figure and Bignefs of the fmall component Parts of Metals and other Ingredients which go to make fuch a Tranfmutation, are; neither is the Secret of uniting them together, as yet found out; we muft think, that if it be true, that fome Chymifts have now and then converted Lead into Gold, it was by juft fuch a Hazard, as if a Man fhould let fall a handful of Sand upon a Table, and the Particles of it fhould be fo ranged that we could read diftinctly on it a whole Page of *Virgil's Ænead.* It is therefore great Folly to attempt to find out fo great a Secret by Reafon or Art; And there is fcarce any Thing more certain than that the Perfon, who would try to hit upon it by Chance, in making a great Number of Experiments, will be ruined firft.

12. Now,

1. *Of fuch a Figure,* &c.) It is probable that the Particles of *Quickfilver* are (*globular*) or cylindrical; which if they be, you may fee how the principal Phænomena of it are to be explained, in *Clerc's Phyficks,* Book II. Chap. 4. Sect. 39.

12. Now if we consider that the Parts of Metals are very solid, we must conclude, that they will resist the Action of Light, and consequently reflect it with its whole Motion; whence it follows, that when Metals are well polished, they ought rather to appear bright than coloured.

12. Why Metals shine.

13. However, Gold and Copper appear each of them to be of a peculiar Colour, the one looking yellow and the other red. But this may proceed from hence, that the component Parts, which consist of original metallick Particles associated together, [1] are bigger than the component Parts of other Metals, and that the Interstices which are left between them, make a considerable Alteration in the Reflexion of the Light. And indeed if there be as much Pains taken to burnish Gold, as is taken to burnish Silver; that is, if the Parts of the Gold which stick up highest, be so ground down by what Artists call a *Blood-stone*, and be made as level as can be with the rest; and the Gold be then looked upon with a Microscope; it will appear very rugged and uneven, and like a great Number of little Mountains ranged on each Side with their Valleys betwixt them; the Situation of which is such, that if the Light be reflected from the Tops of them to any particular Place where the Eye is, there will be none reflected to it from any other Parts of their small Superficies.

13. Why Gold and Copper are of a peculiar Colour.

14. This [2] Interruption which there is between the Parts of Gold, is the Reason why it will very freely permit the Edges of Tools to enter into it, and consequently, why it is easier cut than other Metals.

14. Why Gold is easy to cut.

15. It may without doubt be conceived, that Metals may have all those Properties which we have mentioned, and yet their component Parts not be made up of those Particles which we have said they are made up of: But then it is not so easy to account for the Experiments of Chymists, who by the Resolution of Metals, can draw Salt and Sulphur out of them: So that the Operations of Chymists help to confirm what we have advanced,

15. What we have said about Metals is confirmed by Chymical Operations.

16. But

1. *Are bigger than the component Parts,* &c.) See *the Notes on Chap.* XXII. *Art.* 18. *of the first Part.*

2. *Interruption which there is,* &c.) And makes it to be dissolved by *Aqua Regia*, which will not dissolve Silver. See *the Notes on Chap.* 22. *Part* I. *Art.* 17, *and* 18.

16. Why Metals are Ductile.

16. But however this be, we cannot but think that the component Parts of Metals are long; otherwise we cannot understand how Metals should be so ductile as they are, whether they be [1] forged upon an Anvil, or drawn through a wire-drawing Iron; whereas, if we suppose them to be somewhat long, it is easy to conceive, that when they are pressed on one Side, they will slip sideways of each other without quite separating.

17. Why Metals that have been forged are harder to break Length-ways.

17. Further, it is not possible to conceive, that when a Piece of Metal is continually pressed upon one Way the Parts of it should be able to lye cross; on the contrary, we cannot but think, that they must necessarily so order themselves as to place themselves by each other's Side, and correspond Length-ways to the Length of the whole Piece, which will make it easier to bend that Way than any other; And this agrees with Experience: for Metals which are beaten into Rods upon an Anvil, or drawn into Wire through a Wire-Iron, are very strong Length-ways, but Breadth-ways they are many Times easier to break than Workmen would have them. And we observe Strings in them, as in the Slip of an Ozier.

18. This Property ought not to be in Metal that is not forged.

18. These Strings ought not to be in Metal that is cast and has not been forged: And so we find that cast Metal is as easy to break one Way as another.

19. How Steel is tempered.

19. Steel, which is nothing else but fine Iron, is capable of being made the hardest of all Metals: The Way of making it so is this; only to heat it red-hot in the Fire, and then throw it all at once into Cold Water; and this manner of hardening is what they call *tempering* it, and this makes it capable of cutting or at least of breaking all Sorts of Bodies without Exception, even Diamonds themselves: For it is certain they will break in Pieces with a small Stroke with a Hammer if it hits right.

20. Why tempered Steel is so hard.

20. In order to account for this Effect (which perhaps is one of the most admirable, and doubtless one of the most useful Properties that we know) we must suppose that the Heat of the Fire, which makes the Steel almost ready to melt, puts the small Particles, which each component Part is made up of, into Motion, and thereby causes the Particles of the two nearest compo-nent

1. *Forged upon an Anvil, &c.*) "An Ounce of which (*viz. Gold*) "is spread into seven hundred and "fifty Leaves and above, of four "Inches Breadth each Way." *Plin. Book* 33. *Chap.* 3. But concerning the Ductileness of Gold, See *Chap.* 9. *Part* I. *Art.* 10. *and* 11.

nent Parts, (whose Distance from each other was very small, though far enough) to approach a little nearer one another, so that the Metal becomes more uniform than it was before; after this, being cast on a sudden into the cold Water, the metallick Parts [1] lose the Motion they were in, before they have Time to gather together again into gross component Parts, with considerable Intervals between them: Whence it follows, that the Points or Edges of Gravers and the Teeth of Files can only slip over them without entring into them.

21. How we may make it lose this Hardness.

21. And in order to reduce tempered Steel to the State it was in before, we need only heat it red-hot again in the Fire, and let it cool gradually; for then the Parts which were uniformly joined together, will have Opportunity of reuniting in a great many little Masses or Grains, and leaving as large Intervals between, as there was before the Steel was tempered.

22. Of tempering Iron, and why other Metals cannot be tempered.

22. Iron is capable of being hardened almost as much as Steel, provided it continues in the Fire longer than Steel, before it be put into cold Water; and the Reason why it must continue longer, is, because its Parts are more fixed; and of this we have a sufficient Proof, because Iron is harder to melt than Steel. But other Metals cannot be tempered in this Manner, at least by themselves without any Mixture, because a violent Heat, cannot put their Parts a little in Motion, so as to range them differently, without quite melting them.

23. How a Mixture of different soft Metals may become hard.

23. We find that a Composition of Copper and Tin is very hard and brittle, though each of these Metals separately is easy to cut, and will easily bend without breaking; the Reason of which is, because their different Parts being uniformly mixed together, unite in very small Masses or Grains; whence it follows that they cannot be so closely connected together, in the same manner as a Wall built with small rough Stone is not so compact as one built with large cut Stone: And for the same Reason, the Interstices left betwixt them, are not large enough for the Edges of Tools to enter into; so that they can only slip over them, without loosening any of the Parts.

24. That Rust is nothing else but disturbing the Order of the metallick Parts.

24. We observe also, that Metals are very subject to Rust; Now Rust is nothing else but a Disorder of their Parts, caused by the Action of some strong Liquor, which is in great Agitation, the Parts of which get into the Pores of the little Masses, like so many Wedges;

1. *Lose the Motion, &c.)* See *Hook's Micrography, Observ.* 9.

Wedges: And becauſe theſe Pores are ſmaller in Iron and Steel when they are tempered than when they are not, and for that Reaſon it is then more difficult for other Bodies to enter; we likewiſe conclude, that they are not ſo ſubject to Ruſt.

24. That the Parts of Metal, are not always entirely corrupted by Ruſt.

25. It is to be obſerved alſo, that the ruſty Particles of Metals are not entirely corrupted. For thoſe which come off of Copper, for Inſtance, which we call *Verdegreaſe*, may afterwards be converted into Copper again.

26. Why the Ruſt of Copper and Braſs is the ſame.

26. That *Verdegreaſe* which is made of Braſs, ſhould afterwards be converted into Copper and not into Braſs, is no way inconſiſtent with what has been ſaid: For Braſs is not a real Metal, but only a Compoſition of Copper, and a certain fuſile Stone call'd *Lapis Calaminaris*, mixed together in the Fire. And it is probable, that the *Verdegreaſe* is made only of the Parts of the Copper and not of thoſe of the *Lapis Calaminaris*, which is mixed with it.

27. The Manner of refining Gold and Silver.

27. I ſhall finiſh what I propoſed to ſay concerning Metals with an Explication of the Artifice made uſe of by the *Spaniards* in *Peru*, and other Parts of *America*, to ſeparate the Gold and Silver, from the Dirt and Stones which theſe Metals are found mixed with. Firſt, they beat to a Powder in Mortars, the hard Stones which they dig out of the Mines; then they pour in as much clear Water as is ſufficient to make a very ſoft Paſte, which they ſprinkle with a little Salt and Quickſilver, and then they beat them up together for a conſiderable Time. After this, they waſh the Mixture in ſeveral Waters, which ſeparate all that is not Metal from them, and the Gold or Silver appears at laſt like an *Amalgama*, as the Chymiſts call it, with *Mercury*, which is afterwards made to evaporate with a moderate Heat: And then the Metals become like Aſhes, which they turn into Ingots, by melting them in a Crucible in a very fierce Fire.

28. The Reaſon of this Method.

28. This Method of refining Gold and Silver, is very eaſy to apprehend; For it is evident, that the whole Secret is nothing elſe but to break the ſmall Incloſures, in which the Particles of the Metals are contained; and the Water and Salt do the ſame Office here, as the Water alone does, when dry Plants, out of which we would draw Oyl, are ſteeped in it. And as to the *Quickſilver*, it ſerves to unite and gather together a great many Parts of theſe Metals, which would otherwiſe be in Danger of running off with the Water, as they are waſhed.

CHAP.

CHAP. VII.

Of MINERALS.

THERE are a great many more Things which need to be explained in Minerals than in Metals, and there are alſo a much greater Number of them. For we reckon but ſeven Metals, whereas there are an innumerable Quantity of Minerals; I ſhall here ſpeak only of what ſeems to me moſt probable with Regard to the Nature of thoſe which are moſt common.

1. That there are a great many more Things to be conſidered with reſpect to Minerals, than with reſpect to Metals.

2. Though [1] thoſe Places in the Earth where Metals are formed are very much preſſed upon by the Weight of all that terreſtrial Matter which is betwixt theſe Places and the Surface of it, yet thoſe Parts which are near the Surface are ſo little preſſed upon, that they are ſeparated from one another by an infinite Number of Chops and Chinks, which are open every Way, and which give a free Paſſage to Vapours and Exhalations, and to a great many other Parts of Matter which are put in Agitation, by the Heat which is in the Bowels of the Earth: And becauſe it is the Property of Exhalations to mix themſelves very eaſily with thoſe very fine terreſtrial Particles, which they themſelves looſen; they muſt compoſe a great many little Heaps, the Parts of which, after having been differently agitated amongſt each other, will agree to move all the ſame Way at laſt, which will cauſe them to be at reſt with reſpect to one another. After this, the Body which is thus compoſed, having

2. How Grains of Sand are formed.

1 *Thoſe Places in the Earth where Metals are formed*, &c.) There is a very remarkable Paſſage in *Varenius* which ſhows us the inward Conſtitution of the Earth for a conſiderable Depth, which becauſe it is very well worth Obſervation I ſhall here tranſcribe. ' Upon digging the ' Earth, ſome time ago at *Amſterdam*, two hundred and thirty ' two Foot deep, in order to make ' a Well, the following Sorts of ' Earth were obſerved: Garden-' Mould ſeven Foot; black Earth fit ' to burn, which they call Turf ' (though it is not the true Turf) ' nine Foot; ſoft white Clay nine ' Foot; Sand eight Foot; Earth four ' Foot; Sand, upon which the Houſes ' at *Amſterdam* are built on Piles, ' ten Foot; Clay two Foot; white ' Gravel four Foot; dry Earth five ' Foot; muddy Earth one Foot; Sand ' fourteen Foot; ſandy Clay three ' Foot; Sand mixed with Clay five ' Foot; Sand mixed with Sea Shells ' four Foot; after that a Clay Ground ' to the Depth of a hundred and ' two Foot together; and at laſt Gra-' vel for thirty one Foot more where ' the Digging ended. ' *Varenius Geography*, Book I. Prop. 7.

having a Force sufficient to put the Matter which surrounds it in Agitation, will by Degrees transfer all its Motion to this Matter, and at last be at Rest, being formed into a Figure very nearly round. And this, in my Opinion, is the Method in which *a Grain* of Sand is formed, and in the same Manner innumerable Grains may also be formed.

3. The Properties of Grains of Sand.

3. These Grains are heavy, because they are composed of terrestrial Matter, and they are hard because without Motion: They must be transparent because the small Globules of the second Element, by which they were agitated at first, keep open the Pores for themselves to pass through: However, these Pores are not so many, but that there are a great many solid Parts also to reflect the Light; and because their Superficies are of different Roughness and differently uneven, this causes several Modifications of the Rays of Light, and makes the Grains of Sand to appear of all those different Colours which we observe in them.

4. How Clay is produced.

4. The Production of Clay is not at all different from that of Sand; only we must add, that the Particles of Clay are vastly smaller, so as to leave very little Interstices between them, by which Means it is very difficult for Water to penetrate them.

5. The Reason of the several Sorts of Sand and Clay.

5. Because the Parts that are brought up out of the Earth are not at all exactly alike, nor every where in the same Quantity; and because also the Vapours and Exhalations which bring them up, are not the same every where: it evidently follows, that the Grains of Sand and Clay, cannot be of the same Bigness and Quality every where.

6. Why a Number of transparent Grains compose an opake Body.

6. Though every single Grain of Sand be transparent, yet a great Number of them together compose an opake Body: For the Light in passing through them going several Times out of Air into Sand, and out of Sand into Air alternatively; every Superficies reflects some of the Rays continually, so that at last, there is none left to go on that Way which they at first tended.

7. How Flints, Crystal and Diamonds are produced.

7. Now if the Matter of which a single Grain of Sand is made, meets together in so great a Quantity as to compose a Mass of any considerable Bigness, this Mass will be transparent, and according to the Degree of Hardness which it has, and the particular Rangement of its Parts, it will either form some Flint-Stone, or Crystal, or Diamond.

8. Though all these Bodies are very hard, yet they must notwithstanding that, have been originally liquid: And that they were so appears from hence; that they are all of them of that Figure which Drops of Liquor of the same Bigness, ought to be; and also from hence, that when a great many Pieces of Crystal are found together, as they very often are in the Mountains of *Swisserland*, and in those in the *Milanese*, they are all of the same Figure that little Balls of Paste laid one upon another and pressed together by their own Weight would be: For as every Piece of Crystal, is surrounded and compressed betwixt six others, so it is squeezed into [1] a Body with six Sides very nearly equal.

8. Why almost all the Pieces of Crystal are Solids of six Sides.

9. It may also happen, that some metallick Parts may mix themselves with the Matter of which all these are composed; and if so, this will cause the Light to have particular Modifications given to it, as it falls upon or passes through them, and then the Rays may excite the Sensation of different Colours in us: Wherefore instead of Crystal, Flints, and Diamonds, we may have *Emralds*, *Agats*, *Topazes*, *Rubies*, *Saphirs* and such like Jewels.

9. How Jewels of different Colours are generated.

10. What is here said concerning the Formation of these Sorts of Bodies, may be confirmed from hence, that Art, which imitates Nature, cannot make Glass or artificial Crystal, without a large Quantity either of Sand or Flint dissolved by a violent Heat, the melting of which is promoted by the Ashes of *Kali*, or *Fern*, and such like Plants which contain a good deal of Salt in them. And Enamel, which resembles precious Stones, cannot be made without adding a little Metal to the Matter of which it is composed, which would otherwise be only Glass.

10. A Confirmation of what has been said concerning the Production of Jewels.

11. But it is to be observed; that in order for Crystal and such like transparent Stones to be formed and generated in the Bowels of the Earth, they must not first be hardened into Grains of Sand: For though such Grains might afterwards be softened in the Bowels of the Earth, they could never unite together again, without leaving some Interstices between them which would hinder them from being transparent.

11. That Crystal is not made up of Grains of Sand already formed.

1. *A Body with six Sides very nearly equal*, &c.) "It is not easy "to find out a Reason why it is generated with sexangular Sides, and "the rather because the Points are of "different Sorts, and the Sides are "so perfectly smooth, as not to "be imitated by any Art whatso-"ever.' *Pliny* 37. 2. But for the Reason of this, See *the Notes on Part* I. *Chap.* 22. *Art* 22.

12. How Flint-Stone is formed.

12. It is not easy to understand how Grains of Sand should be softened, but they may easily be joined to each other by some terrestrial Matter which gets into the Interstices that are betwixt them, and so compose a Flint-Stone.

13. A Proof that there is some Matter which unites the Parts of Stone.

13. There is no doubt but that in several Parts of the Earth, terrestrial Matter is carried up along with the Vapours: For we see that the Waters of a great many Fountains, though they are very clear, [1] yet contain such a Quantity of these Exhalations, that in Time they gather together into a large Heap. Thus the Waters of the Fountains of *Issi* and *Arcueil*, contain so great a Quantity of them, that they stick to the concave Superficies of the Pipes through which they run, and form a Sort of Stone very hard and heavy.

14. How Stones are produced.

14. When the Parts of Clay are thus fastened together by the Matter which stops in and fills the Interstices, they compose Stones; which have different Qualities according to the particular Nature of the Clays which are found in different Countries, and that of the Matter which unites them. This appears from hence, that we find Stones in Quarries, where some Years before nothing was digged up but Clay.

15. How Marble is produced.

15. There is no Difference between the Production of Marble and of common Stone, but only this; that the Clay out of which it is made, consists of much smaller Parts, which lie a great deal closer to each other, and consequently the Interstices between them, are more easily filled by the Exhalations which stop in them; so that the Composition is more close and compact than other Stones. Whence it must be very hard and capable of taking a good Polish.

16. That a great many Effects are falsely ascribed to some Stones.

16. From the Nature of Stones both precious and common which we have here laid down, I don't see how we can deduce certain Properties which are mentioned by the Writers of Natural History: As, for Instance, that a Blood-stone, worn by a Person who has the *Bloody-Flux*, will stop the Distemper; and that other Stones will cure other Distempers. And therefore we find by repeated Experiments, that these Sorts of Properties are falsely ascribed to the greatest Part of these Stones. But it is not so with respect to the *Load-stone*; for almost all the Properties thereof related by the Ancients, are found

1. *Yet contain such a quantity of them, &c.)* See the Notes below on Chap. X. Art. 13.

found to be true; and we have moreover found more ſurpriſing Things in it, than were known to the Ancients; but ſo extraordinary a Subject, demands to be treated of by it ſelf.

CHAP. VIII.

Of the LOAD-STONE.

1. What a Load-ſtone is, and whence it is taken.

THESE Stones, which are very much of the Colour of Iron, but much harder and heavier, are taken out of the Iron Mines; they are not all of the ſame Bigneſs, nor of the ſame Figure; for they are found of all Sorts of Figures, and of different Bigneſſes. The firſt Effects taken Notice of, were ſo ſurpriſing to all the Philoſophers, that it was impoſſible to have foreſeen ſuch, upon their Principles of Reaſoning: But not to contend with them now, concerning the little Foundation they had to go upon, and to ſhow the Strength of what I formerly laid down in the firſt Part of this Treatiſe, I ſhall do here as if I were the firſt that had made any Obſervation about the Load-ſtone. And in the firſt Place I ſhall reckon up ſome of its Properties, which I ſhall content my ſelf, with only aſſigning a *probable* Reaſon for; and after that, I ſhall endeavour to eſtabliſh the Truth of my Conjecture, by ſhowing that all the Conſequences that can be drawn from it, agree with Experience.

2. That the Load-ſtone attracts Iron.

2. The firſt ſupriſing Thing in the Load-ſtone, and which perhaps was firſt found out by Chance, is, that if it be placed at a certain Diſtance from a Piece of Iron, the Iron will move out of its Place, and go and join it ſelf to the Load-ſtone, and that ſo ſtrongly, that it will require ſome Force to ſeparate them from each other again. And thus it is ſaid, that the Load-ſtone *draws* Iron.

3. That Iron draws the Load-ſtone alſo.

3. Now in order to ſee if this Attraction be Reciprocal, we muſt contrive that the Stone may be eaſily moved, which is done by putting it on any light Thing in the Shape of a Boat, and then letting it ſwim on the Water. After that, if we hold a Piece of Iron at a certain Diſtance, we ſhall ſee the little Boat move on the Water, and the Load-ſtone come and join it ſelf to the Iron.

4. That the Load-stone endeavours to turn its Poles and its Axis, to one particular Situation.

4. The carefully making this Experiment, has occasioned the Discovery of another Property of the Load-stone, as surprizing as any of the former; and that is, that when the Load-stone is alone in its Boat, and at Liberty to place it self in that Situation which is most convenient for it; it always has a Tendency one particular Way, and turns it self towards one Part, and seems by that Means to affect one particular Situation in the World. For it always turns one of its Sides towards that Part of the Horizon which we call the *North*, and the opposite Side to the *South*: And these two Parts of the Load-stone are those they call its *Poles*, and the straight Line which is supposed to go from one Pole to the other is called its *Axis*.

5. That the Load-stone communicates its Properties to Iron.

5. One of the most surprising Properties of the Load-stone yet, is, that it communicates those Properties now mentioned to the Iron which touches it, or which comes within such a Distance of it: Insomuch that a Piece of Iron which has been touched by a Load-stone, or which has passed very near it, will lift up another Piece; and has also its Poles, which turn towards the same Parts of the World that the Poles of the Load-stone do. For Instance, a Knife which has been rubbed upon a Load-stone, will take up Needles and Nails of Iron or Steel, and the Needles of Mariners Compasses will turn towards the North and South, and the Extremities of them will point to those Parts.

6. That the Iron will acquire a Power to lift up a larger Quantity of other Iron if it be touched in one particular manner.

Tab. XIV. Fig. 6.

6. Upon this Occasion, I shall make some Observations that are of great Importance. And the first is, that a Knife rubbed upon a Load-stone, will have more or less Power to lift up Iron, according to the Part upon which it is rubbed; and that it will lift up most of all, when it is rubbed upon one of the Poles, and moved upon it Length-ways from the Handle to the Point. Thus if the Body G represents a Load-stone, the Poles of which are A and B; the Knife CD will acquire the greatest Force of all to lift up Iron, if it be drawn along the Line FE, so that the Part nearest the Handle, touch the Load-stone first, and the Point touch it last.

7. If the Iron be afterwards rubbed the contrary Way, it will lose all the Virtue which it had acquired.

7. The second Observation is, that if, after it has been touched upon the Load-stone in this manner, and acquired the greatest Virtue to lift up Iron, it be rubbed the contrary Way, that is, if it be moved upon the same Pole of the Load-stone, from the Point to the Handle; we shall with surprise find, that it will in a Moment lose all

all the Virtue which it had acquired, and not be able to lift up any Iron at all.

8. These Obſervations regard the *Attractive Virtue* of the Load-ſtone, as it is called; but as to the *Directive Virtue*, that is, the Virtue by which it places it ſelf in a particular Situation with reſpect to the Heavens; it is to be obſerved firſt, that the Point of the Needle of a Compaſs, which has been touched upon one of the Poles of a Load-ſtone, turns to the oppoſite Part of the Heavens which the Pole it ſelf turns to. For Inſtance, if one End of the Needle touched the South-Pole of the Load-ſtone, that End will turn to the North.

8. That the Point of the Needle does not turn it ſelf to that Part in the Horizon, which the Pole it is touched with turns towards.

9. We may obſerve further, that what has been wrote by ſome Perſons, *viz.* That the Point of the Needle which has been rubbed upon the Load-ſtone and turns towards the North, raiſes itſelf up towards the Pole-Star, is not true; but on the contrary, it bends towards the Earth, as if that Side was become the heavieſt.

9. That that End of the Needle which turns towards the North, inclines towards the Earth.

10. The Needles in Compaſſes are by no Means proper to ſhow us how much this Inclination of the North-Point towards the Earth is, becauſe their Center of Gravity is a great Way below the fixed Point upon which they turn: Wherefore I cauſed a Needle to be made very ſtraight, and through the Middle of it I put a ſmall Braſs-Wire at right Angles to it, which ſerved to ſupport the Needle upon two ſmall *Pivots*, in the ſame manner as the Beam of a Ballance is ſupported by the Handle; both Sides were equally heavy at firſt, ſo that it continued exactly in Æqnilibrio, but after it was touched by a Load-ſtone and placed in the Plain of the Meridian, the Pole which was turned towards the North, weighed down on a ſudden, and did not ſtand ſtill till it inclined to the Horizon near ſeventy Degrees.

10. What the Quantity of this Inclination is.

11. Theſe are ſo many of the Phænomena of the Load-ſtone, as are a ſufficient Ground for us to argue upon, in order to find out what the true Nature of it is; and that there may be no Miſtake, we muſt take care not to mix our own Prejudices, with the Facts and Experiments. Wherefore, to ſpeak ſincerely, and not to be over-haſty in judging, we muſt freely own, that all the Experiments which have been made of the Load-ſtone, and which have raiſed our Admiration ſo much, are nothing elſe but *local* Motion: Thus, for Example, when we ſay that the Load-ſtone draws the Iron, we can diſcover nothing elſe by our Sight, but only that the Iron moves *locally* towards the Load-ſtone; ſo likewiſe, when

11. That the Things which are ſo ſurpriſing in a Load-ſtone, are all nothing but local Motion.

we say, that the Load-stone has a Tendency to one particular Situation in the World; all that appears to us is, that when it is out of this Situation, it moves it self *locally* till it is got into it, and then it continues at rest. This being granted, we may affirm with Truth and Confidence, that to search out whence the Properties of the Load-stone proceed, is nothing else, but only proposing to our selves to find out the Cause of certain *local* Motions which are made when the Iron is placed near the Load-stone, or the Load-stone near the Iron.

12. The general Cause of Motion.

12. And in order hereunto, if we look back to the general Causes of Motion, that is, if we examine what that is which makes a Body which was not in Motion to begin to move, we shall find that Philosophers generally assign two Causes, *viz. Impulse* and *Attraction.* The first of these we can clearly conceive, and it follows from this Principle, acknowledged by every Sect of Philosophers, *That the Parts of Matter are impenetrable by each other, and that a Body cannot move towards any certain Place without pushing forward or displacing other Bodies which are in its Way.*

13. That Attraction is not the Cause of Motion.

13. *Attraction*, taken in the Sense of Philosophers for a particular Cause of Motion different from *Impulse*, is as was before observed, a Thing very obscure, or rather a Thing that we have no Idea of. For though we may imagine that there are some particular Sorts of Motion which may very well be explained by *Attraction*; yet this is only because we carelesly ascribe that to *Attraction*, which is really done by *Impulse*. Thus when we say that a Horse *draws* the Chariot to which he is harnessed, it is really no more than this, that the Chariot is so fastened to a Collar, that the Horse cannot bear forward but he must press upon the Collar, and consequently move the Harness and Chariot which are fixed to it. So likewise, there is no Difficulty in the use of Syringes, Pumps and Syphons, when we once come to understand, that the Motion of heavy Liquors upwards is really done by *Impulse*.

14. It is probable that the Effects of the Load-stone are produced by some very subtle Matter.

14. I do not now undertake to prove that the *Attraction* spoken of by Philosophers, is a Thing purely chimerical; that would carry me too far from my Subject. But because *Impulse* is a Thing very familiar to us, and which we can easily understand; I shall therefore make use of *Impulse* only, for the Explication which I intend to give of the Properties and Effects of the Load-stone. Let us imagine then that when the Iron moves towards

wards the Load-ſtone, or the Load-ſtone towards the Iron, that it is becauſe there is ſomething which impels theſe Bodies towards each other; and becauſe it is very uſual and very eaſy for us to conceive, that a Body which is in Motion can impel another Body; let us imagine, that *that* which impels the Iron towards the Load-ſtone, or the Load-ſtone towards the Iron, is a third Body, or rather a certain Matter which is in Motion, and which is very ſubtle, becauſe it cannot be perceived by our Senſes.

15. How this Matter is moved.

15. Though we are at Liberty to ſuppoſe ſuch a ſubtle Matter as this, yet we are not at Liberty to aſcribe what ſort of Motion we pleaſe to it. The particular Situation which Load-ſtones or Needles rubbed on Load-ſtones take, (they always turning to the North or South,) forces us to acknowledge that this Matter either moves from North to South, or from South to North, or perhaps both Ways. Further, the Inclination of the Needle after it is touched by the Load-ſtone, whereby it tends towards the Earth on the North-Side, muſt make us think, that the Matter which moves from North to South, moves upwards, and that the Matter which moves from South to North, moves downwards.

16. What this Matter is.

16. All this might paſs only for Conjecture, if we had not elſewhere ſhown, that there muſt neceſſarily be ſome Matter which has theſe Properties. For if we call to Mind that Matter which we formerly ſaid deſcended from the Heavens, out of thoſe Parts which are near the Poles of the Earth's Vortex in the Form of a great many little Screws, which enter into the Body of the Earth through the Pores which are parallel to its Axis, we ſhall have Reaſon to think that this Matter is capable of producing theſe Effects: For thoſe of theſe little Screws which are entered in through the Northern Hemiſphere, when they come out into the oppoſite Hemiſphere, cannot but do one of theſe three Things; *viz.* either they muſt continue to move ſtraight on into the Heavens, or they muſt return back immediately into the Earth, or elſe they muſt go round about its Superficies in the Plains of different Meridians, and ſo mixing with the cœleſtial Matter enter again into the ſame Pores which they before paſſed through. Now the firſt of theſe is impoſſible, becauſe the Interſtices which are between the Globules of the ſecond Element that is in theſe Places, are already filled with the ſame ſort of Matter, which has a perpetual Tendency to deſcend towards the Earth. So likewiſe it is impoſſible, that theſe ſmall

Screws ſhould return back again into the Earth, either through the ſame Pores which they came out at, by going the direct contrary Way to what they went before; becauſe theſe Pores are always full of the ſame ſort of Screws, which have a perpetual Tendency to go out; or through the Pores into which thoſe Particles which deſcend immediately from the Heavens enter, becauſe theſe laſt ſort of Screws being turned the contrary Way to the other, require Pores, the Nuts of which are formed quite different, ſo that what will paſs through the one will not paſs through the other. We muſt conclude therefore, that this Matter continues to move along the Surface of the Earth, in the Plains of all the Meridians in order to re-enter into the ſame Places which it entered in at before.

17. That the magnetick Matter moves in the external Part of the Earth in the ſame manner as it does in the Air.

17. What has been ſaid of the Matter which enters into the Earth out of the Northern Hemiſphere, ought equally to be underſtood of that Matter which enters into it out of the Southern Hemiſphere. But it is to be obſerved, that when I ſpeak of the Surface of the Earth upon which this Matter continually moves, I mean that of the *Interiour* Earth; For I not only place the Air above this Surface, but alſo a conſiderable Thickneſs of that *outward* Earth upon which we dwell, which is at it were a Cruſt or Bark, which contains in it the inward Earth: So that the Matter which we are ſpeaking of, and which we ſhall hereafter call the *magnetick* Matter, moves within this exteriour Earth, in the ſame manner as it does in the Air, and in both of them it moves the contrary Way to what it does in the internal Earth.

18. Of the Nature of the Load-ſtone in particular.

18. This being ſuppoſed, we may imagine the particular Form of the Load-ſtone to conſiſt herein; that there are an innumerable Multitude of Pores made in this Stone which are parallel to each other, ſome of which are of the Shape of the Nuts of Screws which let the ſmall Screws that come from the North-Pole enter in, and others of the Shape of ſuch Nuts as will let thoſe little Screws which deſcend from the South-Pole paſs through them.

19. Of the Nature of Iron.

19. As to the Iron or Steel; we can eaſily conceive that they have alſo both theſe Sorts of Pores, but that they are commonly ſtopped by the fineſt Parts of the Metal which ſtick up in them like ſo many little Hairs; ſo that we may call Iron an imperfect Load-ſtone, and affirm them to be both the ſame ſort of Bodies. Which is confirmed by what was before ſaid, that Load-ſtones are found

found in the Iron Mines, and that they may be converted into a very fine Steel by the Help of Fire.

20. The only Difference that I need take Notice of here between Iron and a Load-ſtone, is that Iron is very pliable, and that its Parts can be bent backwards and forwards ſeveral Times together before it will break; whereas, the Load-ſtone is very ſtiff, and its Parts will not bend without breaking.

20. The Difference between Iron and a Load-ſtone.

21. The few Suppoſitions which I have made in order to explain the Nature of Iron and of the Load-ſtone, are nothing compared with the great Number of Properties, which I am going to deduce from them, and which are exactly confirmed by Experience. The firſt that offers it ſelf, is the Situation of the Load-ſtone it ſelf and of Needles touched by it, which ſo order themſelves, that one of their Poles looks towards the North, and bends on that Side towards the Earth, and the other looks towards the South, and raiſes it ſelf up to the Heavens. And this muſt neceſſarily be; becauſe if the Load-ſtone be in any other Situation, the Magnetick Matter will in vain ſtrike againſt its Superficies, and not be able to enter in, and ſo will cauſe it to alter its Situation till the Length of its Pores coincide with the Lines deſcribed by the magnetick Matter. After which it is manifeſt, that it muſt continue in this Situation, becauſe it no longer makes any Reſiſtance to the Motion of the Magnetick Matter.

21. Why the Load-ſtone turns to one particular Part in the Heavens.

22. Now becauſe the Inclination of the Line deſcribed by the magnetick Matter, is different in different Places of the Earth's Superficies, ſo that the nearer we are to the Equinoctial Line, the nearer it is to being parallel to this Superficies; and to thoſe who are under this Line it is exactly parallel to their Horizon, and to thoſe who live in the Southern Parts of the Earth, it inclines the contrary Way to what it does in the Northern Parts; it follows, that the Load-ſtone or the Needle touched by it, ought not to have the ſame Inclination every where; but that whereas the End of the Needle which points towards the North, inclines to the Horizon about ſeventy Degrees at *Paris*; this Inclination ought to be found ſo much leſs as the Places where the Obſervation is made, are nearer to the Equator; That under the Equator there ought to be no Inclination at all, and that beyond the Equator that End which points towards the South ought to encline towards the Earth. All which have been confirmed by an infinite Number of Experiments

22. That the Load-ſtone ought not to have the ſame Situation all over the Earth.

ments made by a great many Pilots, who never dreamt of philoſophizing about the Nature of this Stone. For when they had ſo ordered the Paſte-boards of their Compaſſes in which the Needles are incloſed, that they might hang in equilibrio upon their Pivots, before they were touched upon the Load-ſtone; and when they had put pieces of Wax upon thoſe Ends of the Paſte-boards which looked towards the South, to hinder the Needles from inclining after they were touched; in order to preſerve this Equilibrium, they have been forced to take off theſe pieces of Wax by Degrees as they drew nearer to the equinoctial Line, and to put them on the other Side of the Paſte-board as they went Southward of the Line. All which is a certain Sign, that without this Wax, the Needle would have had all thoſe different Inclinations, which we have mentioned above.

23. Why the magnetick Needle does not point to the North and South in ſome Countries.

23. It is evident that the magnetick Needle (whatever be done to it to make it parallel to the Horizon where we are) therefore points to the North and South, becauſe the magnetick Matter which comes out of the Earth moves from the North to the South at the ſame Time that it aſcends upwards; and becauſe this Matter is turned out of its Way leſs, when it enters into an horizontal Needle ſituate in the Plain of the Meridian, than if the ſame Needle were in the Plain of any other *Azimuth*; And hence it follows, that if a Compaſs be carried very near to either of the Poles of the Earth, the Needle will turn it ſelf indifferently to any Part of the Heavens, becauſe in theſe Places the magnetick Matter moving in Lines perpendicular to the Surface of the Earth, it will not turn it ſelf to enter into an horizontal Needle any more when it points toward the North, than when it points towards any other Part of the Heavens. And this was found true by certain *Dutch* Pilots, who attempted to find a North Paſſage into the *Eaſt-Indies*; for when they came pretty near the Pole, their Compaſſes were of no uſe to them, becauſe the Needle turned to all Parts of the Heavens indifferently.

24. How one Load-ſtone may drive another from it.

Tab XIV. Fig. 7.

24. Having thus ſpoken of the Load-ſtone and of magnetick Needles with reſpect to the Earth, let us now compare two Load-ſtones together, and ſee what ought to happen when they are placed by each other in different Manners. And firſt, let us ſuppoſe a Load-ſtone as C, ſwimming upon the Water in a little Boat, in which it is ſo ſituated, that its Axis is perpendicular to the Horizon, and the Pole a, which at other Times turns it ſelf towards

towards the North, is turned towards the Earth, and its opposite Pole b, towards the Heavens; then let us suppose another Load-stone as D, whose Pole B is that which commonly turns towards the South, be presented to the Pole b of the former Load-stone. This being done, we must consider, that the magnetick Matter, which enters in at A, and comes out at B, may also enter in at a, and come out at B, but cannot enter in at b, and come out at a; because the magnetick Matter which comes out of the Earth perpetually, and moves from a, to b, always hinders it; and because there are certain Particles in the Pores of every Load-stone which like so many small Hairs are placed in such a manner as freely to open a Passage for the magnetick Matter when it moves one Way; but to rise up and stop the Pores, if the magnetick Matter attempts to move the contrary Way. For the same Reason we ought to conclude, that the magnetick Matter which comes out of the Pole B of one Load-stone, cannot enter into the Pole b of the other Load-stone. So that the Motion and Effort made by the Matter which comes out of these Stones, tends to make them push and drive away each the other, so that *that* which is at Liberty in the Water, runs away, as if they were at Enmity with one another.

25. How one Load-stone may seem to draw another to it.

25. Let us suppose again, that the Load-stone C swims upon the Water as before, and whereas the Pole B was then presented to the Pole b, let the Pole A be now presented to the Pole b, so that the North-Pole of one Stone may be against the South-Pole of the other. This being done, we are assured in the first Place, that the magnetick Matter which comes out at A being able to enter in at b, and that which comes out at b being able to enter in at A, there can be no Reason why these two Stones should remove from each other. On the contrary, if we consider that the magnetick Matter, which passes reciprocally out of one of these Stones into the other, is continually driving away the Air which is betwixt them, and which crosses its Passage, in order to make Way for it self to move more freely; and because the World is full, this Air having no where to retire but behind the Stones, where by pressing upon them it makes them draw nearer each other, that the magnetick Matter may move with the greater Ease: Hence we may easily foresee, that *that* Stone which is at Liberty, must be impelled towards the other, by the Air which is driven

out of its Place, ſo that it will ſeem to be drawn by it. [1]

26. That is the South Pole of the Load-ſtone that looks towards the North.

26. Since we acknowledge that the internal Earth has exactly the ſame Pores as thoſe from which the Nature of the Load-ſtone ariſes, we may affirm with others that the *Earth* is a *great Load-ſtone.* Wherefore, if we conſider that it is the *South*-Pole in one Load-ſtone, which turns it ſelf to the *North*-Pole in the other Load-ſtone, and the *North*-Pole which turns it ſelf to the *South*-Pole; we muſt allow, that in the Load-ſtone, it is the *South*-Pole which looks towards the *North*, and the *North*-Pole which looks towards the *South*.

27. How the Load-ſtone draws Iron.

27. For the ſame Reaſon that one Load-ſtone moves towards another, Iron when it is at a due Diſtance ought to approach towards a Load-ſtone; if the Weight be not too great, or if it be not hindred by ſome other Cauſe. For Iron being it ſelf an imperfect Load-ſtone, it becomes as it were a perfect Load-ſtone, when it is within the Sphere of Activity of one of theſe Stones; becauſe the Magnetick Matter which comes from thence, opens the Pores of the Iron, and then it reſembles a Load-ſtone. And what we have now ſaid of Iron with Reſpect to the Load-ſtone, holds the ſame concerning the Load-ſtone with Reſpect to the Iron, ſo that either of them that is at Liberty muſt move towards the other.

28. It

1. The learned Mr. *Le Clerc* propoſes a very great Difficulty here. *Phyſ. Book* II. *Chap* 6. *Sect.* 5. 'Becauſe a Load-ſtone conſiſts of 'the moſt ſolid Matter that is, there 'is no doubt but that there are a 'great many more ſolid Parts than 'there are Pores in it. Wherefore 'when two Load-ſtones are placed 'near each other, the magnetick 'Matter which comes out of one, 'and ſtrikes againſt the other, finding more ſolid Parts than Pores, 'ought to move them from each 'other. For the Force of that Matter which daſhes againſt the ſolid 'Stone, with ſo much Vehemence, 'and in ſo great a Quantity, is greater 'than that of the Air can be, which 'it moves out of its Place, and 'drives to the external Poles of the 'Load-ſtone, eſpecially if we conſider 'that the Air abounds with ſo many 'Pores, as will afford this Matter a 'free Paſſage through it.' Thus far He. But, firſt, if one of the Load-ſtones be never ſo ſolid a Body, the other is as ſolid, and therefore there are Pores enough in the latter, to receive all the Matter that can come out of the Pores of the former. Secondly, if the Pores of two Load-ſtones do not all of them anſwer to each other, yet ſome of them certainly do, and therefore part of the Matter which comes out of one Stone will enter into the Pores of the other, and the reſt of the Matter will be very far from being able to remove them from each other. Eſpecially, when, Thirdly, it has removed the Matter between them out of the Way; and therefore the Matter which is behind the Load-ſtones, muſt impel them towards each other. Though perhaps there is a real Attraction between them. See *the Notes on Part* I. *Chap.* 11. *Art.* 15.

28. If any one doubts whether the Load-ſtone has any Communication with the Iron, though it does not immediately touch it, he may eaſily be ſatisfied in this Particular by Experience. For if he takes but the Needle of a Mariner's Compaſs, for Inſtance, (which is converted into a perfect Load-ſtone, by having been drawn over the Pole of a Load-ſtone one particular Way,) and draws it the contrary Way over the ſame Pole, or the ſame Way over the contrary Pole, not touching the Stone but holding it an Inch Diſtance, he will ſee the Needle turn the quite contrary Way to what it did before, and its *South*-Pole will become its North-Pole.

28. That the Load-ſtone may make ſome Alteration in the Iron without touching it.

29. It is eaſy for any one, who underſtands how the Load-ſtone draws Iron, to ſee how a Knife rubbed upon a Load-ſtone lifts up Nails and Needles. Neither will it appear at all ſtrange to ſuch an one, that when the ſame Knife is drawn quick over the Pole of the Load-ſtone the contrary Way to that it paſſed before, it commonly loſes its Vertue of drawing or lifting up Iron. For we know that the Knife became a perfect Load-ſtone only by paſſing at firſt over the Pole of the Load-ſtone, when the magnetick Matter opened its Pores, and bent down the metallick Parts which ſtuck in them, one particular Way; wherefore it is eaſy to imagine that it muſt loſe this Quality of a perfect Load-ſtone, by paſſing over that Pole the contrary Way, becauſe the magnetick Matter does the contrary to what it did before, and raiſes up thoſe metallick Parts which it depreſſed.

29. How a piece of Iron rubbed upon a Load-ſtone draws another piece of Iron; and why it loſes its Virtue when drawn the contrary Way.

30. And this will appear to the Eye to be ſo, if any one has the Curioſity to make or to ſee the Experiment. For, if we put ſome Filings of Iron or Steel upon a Piece of Paper, and move a Load-ſtone over them, we ſhall ſee the Filings place themſelves one upon another, and become like ſo many little Hairs bending all one Way; and if after this, we move the ſame Part of the Load-ſtone, the contrary Way under the Filings; we ſhall ſee the ſame Hairs riſe up and bend the contrary Way to what they did before.

30. An Experiment to ſhow the Alteration which the Load-ſtone makes in the Iron, when it is rubbed the contrary Way.

31. The Iron would not deſerve the Name of a perfect Load-ſtone, if we did not ſee all the Properties of a Load-ſtone in it. Thus, it is not ſufficient, that it draws Iron as we ſee it does, nor that it has Poles as we find by the Needles of Mariners Compaſſes: its Poles ought alſo to turn towards or to turn from the Poles of a Load-ſtone, as we have ſeen two Load-ſtones do when placed near each other: And this is to be ſeen evi-

31. That Iron touched by a Load-ſtone ought to have all the Properties of this Stone.

dently

dently in ſewing-Needles; For if ſuch a Needle be held by a Thread at a certain Diſtance from a Load-ſtone, it will go immediately to the Load-ſtone, and its Point will acquire the Vertue of the*Pole oppoſite to the Pole of the Load-ſtone to which it is joined: Thus, if it joins it ſelf to the *North*-Pole of the Load-ſtone, it will acquire the Vertue of the *South*-Pole, ſo that if afterwards the *South*-Pole of the Load-ſtone be preſented to it, it will turn away from it as if it had an Averſion to it.

32. What the Sympathy and Antipathy between the Load-ſtone and the Iron is.

32. This is what ſome have called the *Sympathy* and *Antipathy* betwixt the Load-ſtone and Iron, which may be obſerved another Way. If we take a Piece of a broken ſewing-Needle, and put it upon a Piece of Paper or Glaſs, and then place one of the Poles of a good Load-ſtone underneath, we ſhall ſee the Piece of Needle ſtand up upon one End; and if we turn the other Pole of the Load-Stone to it, it will immediately change its Situation, and turn the other End up.

33. How the End of a Needle which has acquired the Vertue of one Pole, may acquire the Vertue of the oppoſite Pole.

33. But it is to be obſerved, that if the Point of the Needle hanging upon a Thread (which we mentioned juſt now) be made to touch the Pole of the Load-ſtone which it ſeem'd to flee from before; then it will afterwards go towards this Pole and flee from the other. The Reaſon of which is, becauſe the great Quantity of magnetick Matter which comes out of the Load-ſtone with Violence, forces that ſmall Quantity which paſſes through the Pores of the Needle to go back and to move the contrary Way to what it did before; to which the Suppleneſs of the Parts of the Iron or Steel contributes, becauſe they will very eaſily bend, ſo as to make no Reſiſtance at all to the new Determination of the magnetick Matter.

34. Why this Property is not in the Load-ſtone.

34. The Parts of the Load-ſtone being very ſtiff, it is impoſſible to bend them, or alter them from what they were at the firſt Formation of the Stone. So that the magnetick Matter muſt always paſs the ſame Way in them. And that which is once the *North*-Pole of a Load-ſtone, ought never to become the *South*-Pole, by being placed before the *South*-Pole of a bigger Stone. And this alſo is confirmed by Experience.

35. That Iron may acquire the Vertue of a perfect Load-ſtone without being touched by a Load-ſtone at all.

35. By all that has been hitherto ſaid, it is eaſy to ſee; that all the Vertue which is aſcribed to a Load-ſtone, ought to be aſcribed to the *magnetick Matter* which paſſes through it: But becauſe this Matter paſſes out of the Earth into the Load-ſtone through the Air, it follows, that if a long Piece of Iron be ſo plac'd in the Air, that its Length very

very nearly correſponds with any of thoſe Lines which are deſcribed by the *magnetick Matter*, it muſt in Time acquire the ſame Vertue, which a Load-ſtone by touching it gives it in a Moment. And this we find to be ſo in all Sorts of Iron, which has for a long Time had one End turned towards the Ground or towards the *North*. Thus a Pair of *Tongs* which we take up the Coals with, and which we generally ſet upright, always has at the lower End, the ſame Vertue as we find in the *South*-Pole of a Load-ſtone, and it will attract the *North*-Pole of a Mariner's Compaſs-Needle, that is, that Pole which looks towards the *South*, and the upper-End has the Vertue of the *North*-Pole, and will attract the *South*-Pole of the Needle or that Pole which looks towards the *North*.

36. That altering the poſition of the Iron, changes the Vertue of the Poles.

36. It is to be obſerved, that in Order for theſe Experiments to ſucceed, the Poſition of the Tongs muſt not be changed; for if they be turned upſide down, that End which is next the Ground, will acquire the contrary Vertue to what it had before, becauſe the magnetick Matter will take a different Courſe in the Tongs, and move the contrary Way to what it did before: Thus, that End, for Example, which before attracted the *South*-Pole of the Needle, will now attract the *North*-Pole.

37. How it may in a moment acquire the Vertue of a perfect Load-ſtone without being touched by one.

37. Now upon conſidering the Vertue which the Iron acquired in Length of Time only by its Situation with Reſpect to the Earth; I imagined that a long ſlender Piece of Steel might be made to acquire the ſame Vertue immediately if after it was heated red-hot in the Fire, it were dipped into the Water perpendicularly; For I thought, that when the whole Piece of Steel was thus in the Fire, its Parts would be made very flexible, and conſequently [1] might eaſily be bent by the magnetick Matter ſo as to make no Reſiſtance to its Paſſage through it; after which, being cooled all on a ſudden in the Water, I conceived that the great Hardneſs which it acquired by this Means, would make it keep every Thing the more ſtrongly in that State they were put into; And indeed I was not deceived in my Conjecture; for I found in the firſt Place, that the Steel thus tempered, preſerved at each

1. *Might eaſily be bent, &c.*) So likewiſe, if an Iron Rod be held perpendicularly, and the upper-End of it be ſtruck with a Hammer, that upper-End will become the North-Pole, and the lower-End the South-Pole, becauſe when its Parts are ſhaken in this manner, they are the eaſier moved out of their Places, and open a Paſſage for the magnetick Matter.

each End the Vertue of that Pole, which it acquired in the tempering; and that the End which was towards the Ground, while it was tempering, continued to be always the *South*-Pole, though it were afterwards turned upſide down. *Secondly*, I obſerved that this Steel had not only a Power to move the Needle of a Sea-Compaſs, which is very eaſy to move becauſe it turns upon a Pivot; but that it would take up and carry along with it, as much Filings of Iron or Steel as it would have done if it had been touched by a Load-ſtone of a moderate Strength.

38. A Proof that it is only the Situation of the Iron which makes it acquire the Vertue of a perfect Load-ſtone.

38. Further, to take away all Suſpicion that the Piece of Steel acquired this Vertue, not from its Situation with Reſpect to the Earth, but becauſe the lower-End of it was firſt tempered in the Water; I cauſed another Piece to be heated red-hot, and holding it ſo with the Tongs perpendicular to the Horizon, I poured the Water upon it ſo that the upper-End was tempered firſt. But notwithſtanding this, I found that the Ends of it, acquired the ſame Vertue, as they did when tempered in the former Manner.

39. Why Iron which has acquired the Virtue of a perfect Load-ſtone, will yet take up but a little other Iron.

39. It may perhaps ſeem ſtrange to ſome, that a Piece of Iron which has been for a great many Years together in a Situation proper to acquire the Vertue of lifting up other Iron, ſhould yet acquire ſo ſmall a Degree of it, that the Croſs which had been for above a hundred Years upon the Steeple of the chief Church of *Aix* in *Provence*, having been blown down in a Storm and broken into ſeveral Pieces; none of theſe Pieces, though pretty large, would without Difficulty take up a very ſmall Nail. But this will no longer appear ſtrange, if we conſider that it is the internal Earth, which is very deep in, that we eſteem as a great Load-ſtone; and that the greateſt Part of the magnetick Matter which moves about it, moves within the external Earth, which is like a Shell and contains the other in it; ſo that but a very little of this Matter reaches to the Surface of the Earth; wherefore there always paſſes a great Deal more of it, through a good Load-ſtone than there does through ſo much Air of the ſame Bulk. Whence it follows evidently, that when a Piece of Iron is rubbed upon a Load-ſtone, a much greater Number of its Pores are opened, than would be opened, if the ſame Piece of Iron ſtood a great many Years in the Air without coming near any Load-ſtone.

40. Now to prevent all the Difficulties which might here be raiſed, we muſt underſtand, that beſide the magnetick Matter which paſſes out of the Earth into the Load-ſtone in Order to go out of the Load-ſtone into the Earth again, there is always a certain Quantity of this Matter which moves in and about a Load-ſtone, and which makes a Sort of a Vortex round it. The Reaſon of which is, that this Stone being taken out of the Place where it is generated, as full of the magnetick Matter as it can be, it is eaſier for this Matter to return back and enter again into a Body whoſe Pores are all open to it, than for it to continue its Motion on in the liquid Air, the Parts of which being in perpetual Motion, thoſe of them which come croſs the magnetick Matter are no ſooner removed by it, but there come others immediately, and make the ſame Reſiſtance to it.

40. That there is always a Vortex of magnetick Matter turning about a Load-ſtone.

41. But leſt any one ſhould think, that the inviſible Vortex of this magnetick Matter, which is continually moving about every Load-ſtone, is only a mere Imagination, and not a real Thing exiſting in Nature; we need only obſerve the different Poſition of the Needle of a Sea-Compaſs, when it is variouſly expoſed to a Load-ſtone: For we ſee, that when it is right againſt the Poles of the Load-ſtone, the Length of it coincides exactly with the Axis of the Load-ſtone, and as it is moved round it, it has different Inclinations, and all thoſe ſeveral Sorts, which we before ſaid the Needle in the Compaſs has in all the ſeveral Places of the Earth which are under the ſame Meridian.

41. A Proof that there is a Vortex of magnetick Matter about every Load-ſtone.

42. We ſhall be ſtill further convinced of this Circulation of magnetick Matter about a Load-ſtone, if we conſider how the Filings of Steel or Iron diſpoſe themſelves when they are let fall upon a Piece of Paſte-board which has a Hole in it, where a Load-ſtone is ſo put that its Axis is exactly in the Plain of the Paſte-board; for the Diſpoſition and Rangement of the Filings being exactly ſuch as is repreſented in the Figure, there can be no Room to doubt, but that beſides the magnetick Matter, which paſſes along the Axis AB, and which goes ſtreight on in the Air, there is ſome other alſo which going out at F, G, returns by I, H, towards D, E, and alſo, that there is ſome which comes out at D, E, and returns by I, H, towards F, G.

42. Another manifeſt Proof of this. Tab. XIV. Fig. 8.

43. Such a Sort of Order or Diſpoſition as is here repreſented, is obſerved in all Load-ſtones, if they are homogeneous or every where alike: But if they are not ſo, and

43. The Poſition of the Steel-Duſt about an extraordinary

Load-stone. Tab. XV. Fig. 1.

and their Veins are interrupted or irregular, then the Dust will range it self differently according to those Veins of the Load-stone. And this I have tried a great many Times in a Load-stone like that drawn in the Figure, the Veins of which went winding about, very irregularly, because they were interrupted by some foreign Matter which was got in and which separated them. For having set it in Paste-board, and let the Dust fall upon it, I always observed, that the Dust disposed it self about it, not uniformly every where, as in others, but very differently, according to the Irregularity of the Veins, with which it began a great many different Circles in some Places, and ended them in others; Thus, the Dust which fell about C, made Circles with the Veins A, D, and that which fell about E, made other Circles with the Veins B, F.

44. The Alteration which is made in the Steel Dust sprinkled about one Load-stone, by another Load stone. Tab. XIV. Fig. 8.

44. The Irregularity which appears in the Disposition of the Steel-Dust about this extraordinary Load-stone, is without doubt, a very strong Argument, that there is a Vortex of magnetick Matter about every Load-stone: Let us now try if we can foresee what ought to happen upon differently placing another Load-Stone near that in the Figure belonging to *Art.* 42. And in the first Place, let us suppose the *South*-Pole of one of the Load-stones looking to the *North*-Pole of the other; then because the magnetick Matter which comes out of one of these Load-stones is capable of entring into the other, and will rather enter into it, than turn about and go back to enter in where it went through before; for this Reason, I say, the Steel-Dust, which before was near one Pole of the first Load-stone, and which had gone forward in a streight Line in the Air as far as it was able, and then turned it self on each Side and bent back in order to convey the magnetick Matter round to the Places near the other Pole, that it might enter there; ought to unbend itself again, in order to go streight on to the second Load-stone; and so we find by Experience that it does.

45. Another Alteration made by turning the opposite Pole.

45. The contrary ought to happen, if the *North*-Pole of one Load-stone be applied to the *North*-Pole of the other, or the *South*-Pole of the one to the *South*-Pole of the other. For then the magnetick Matter which comes out of the first Load-stone not being able to enter into the second, will also not be able to go on freely in a streight Line, because it will meet with Resistance from the Matter which comes out of the second Load-stone;

wherefore

wherefore it muſt bend and turn about ſooner than it would otherwiſe do: and ſo turn back the Steel-Filings ſhorter than they were before, that they may go a nearer Way to the oppoſite Pole of the firſt Load-ſtone. And ſo we find it really does.

46. The Alteration made in the common Diſpoſition of the Courſe of the magnetick Matter, may alſo be obſerved in another Manner, which is very proper to give us a true Notion of it: We muſt take a Load-ſtone and put one of its Poles to a Heap of Iron or Steel-Filings, ſo as that it may take up as much of them as it can carry; then holding the Load-ſtone ſo that the Pole which is loaden with Filings be turned towards the Earth, let the Poles of another Load-ſtone be alternately applied to it. This being done, when the different Poles of the two Load-ſtones look towards each other, the Filings of Steel which is upon one of them, and which ſtand upright like ſo many large ſtradling Hairs coming out of the Load-ſtone, will bend themſelves inwards, and get nearer to each other as if they were about to unite together: On the other Hand, when the ſame Poles of the Load-ſtones are turned towards each other, the ſame Filings will bend themſelves outwards, and divaricate from each other a great Deal more than they did at firſt.

46. Another way of obſerving theſe Alterations.

47. By conſidering in this Manner the Diſpoſition of the Steel-Filings about a Load-ſtone, it is eaſy to find out which are the Poles of this Stone. For it is plain that the Poles are the Extremities of that Pore by which the magnetick Matter, which turns leaſt, or which goes the moſt directly that can be from *North* to *South* or from *South* to *North*, enters in and goes out: And conſequently the whole Length of this Pore may be taken for the Axis of the Load-ſtone: Thus in the Load-ſtone DEFG repreſented in the Figure, A and B are the Poles, and the Pore AB is the Axis, which you ſee paſſes through the Middle of all the reſt.

47. An exact way to find out the Poles of a Load-ſtone. Tab. XIV. Fig. 8.

48. But if this Load-ſtone be ſawn in two Pieces along the Axis, we muſt conclude, that each of the Pieces, as for Inſtance C, muſt have its particular Poles, *viz.* the Points which are in the Middle of the Sides AE, FB, through which the magnetick Matter enters in and goes out; for it is in theſe Places that the Paſſage of the magnetick Matter divides it ſelf, there being but half the Matter which comes out of one of the Sides, *viz.* that only which comes out of the Pores near E, which goes along by H towards FB; the other half which comes out of the

48. How the Parts of the ſame Load-ſtone have their particular Poles. Tab. XIV. Fig. 8.

the Pores near A, goes along towards BF by L, which is a ſhorter Way than going by H. We may be convinced of the Truth hereof, by ſprinkling ſome Steel-Duſt about the Load-ſtone AEFBGD put into a Hole in a Piece of Paſte-board in the Manner before deſcribed; for then if one Half of it be taken away, *viz.* that marked K, and the other Half be left, we ſhall ſee the Steel-Duſt part it ſelf in the Manner now mentioned.

49. That the two Pieces of a Load-ſtone ſawn parallel to the Axis, muſt be placed by each other, the contrary way to what they were before they were cut. Tab. XIV. Fig. 8.

49. Now if the Pieces C and K of the Load-ſtone ſawn aſunder in this Manner, be joined together again, by being laid one upon another; it is evident, that the magnetick Matter, which comes out of the lower-Part, cannot enter into the upper-Part, without going a great Way about; but if the Half marked K be turned the contrary Way to the other Half, the Matter which comes out of the *South*-Pole AE of the lower Piece, can enter in at BG the *North*-Pole of the upper Piece, and ſo take the neareſt Way that can be: Wherefore if the Piece K be ſuſpended on a Thread; and let down ſoftly upon C that Way which they were originally joined together; it is very pleaſant to ſee, that a little before they touch one another, the Piece K will turn it ſelf round to the quite contrary Poſition, in Order by that Means to facilitate the Courſe of the magnetick Matter.

50. Of the Diſpoſition of the Steel Duſt, about theſe two Pieces of a Load-ſtone.

50. And if, after theſe two Pieces C and K are thus joined together the contrary Way to what they were naturally, ſome Filings of Steel be ſprinkled about them; then the Ranks formed by them will be like ſo many Semicircles terminated by the two adjoining Poles of the two Pieces of Load-ſtone, the Center of which is the Extremity of the Line where the two Pieces are joined.

51. That two Points which touch one another in the ſame Load-ſtone, become two Poles, the Vertues of which are contrary. Tab. XV. Fig. 2.

51. If a Load-ſtone be ſawn aſunder, ſo that the Plain of the Section be perpendicular to the Axis, then the two Parts do not require a different Situation from that which they had before they were ſeparated; becauſe the magnetick Matter which comes out of the one, can enter into the other the moſt conveniently that can be; but the two Points which touched one another before the Load-ſtone was cut, will become Poles of a quite contrary Vertue. Thus, if the Load-ſtone ACBD, whoſe Axis is AB, the *South*-Pole A, and the *North*-Pole B, be cut along the Plane CD; the Point b and the Point a, which touched one another before the cutting, will become two Poles of contrary Vertue; that is, the Point b will become the *North*-Pole of the Half E, and

the Point a the *South*-Pole of the half F. For, all that magnetick Matter which came from the *South*, and entered into the whole Load-ſtone at the Pole B, ought afterwards to enter into the Piece E at b; and all that Matter which came from the *North*, and entered in at A, ought to enter into the Piece F at a. All this may eaſily be confirmed by Experience, by making either of theſe Pieces E or F ſwim upon the Watter in a little Boat, or by turning the Points b and a one after another, towards the Needle of a Compaſs. For then we ſhall ſee the Point b of the Piece E always turn it ſelf to the *South*, and that it will draw the *South*-Pole of the Compaſs Needle towards it; and the Point a of the Piece F always turn itſelf to the *North*, and draw the *North*-Pole of the ſame Needle. From whence it follows, that they are guilty of a very great Abſurdity, who think that the two Halves of the ſame Load-ſtone, have two entirely different Inclinations, and that one of them tends with its whole Force towards the *North*, and the other on the contrary, towards the *South*; but that when the Load-ſtone is actually cut in two Pieces, each of the Pieces has no longer the *directive* Virtue which was in the whole Stone.

52. Of the Armour of the Load-ſtone, and why an armed Load-ſtone lifts up more Iron. Tab. XV. Fig.

52. Thus we have ſeen how all the *Properties* of the Load-ſtone, hitherto mentioned, have been deduced from the *Nature* aſcribed to it. It is otherwiſe with reſpect to the *Armour*; and it is very ſurpriſing, that two ſmall Pieces of Steel, ſuch as CD, EF, placed as you ſee in the Figures at the two Poles of the Load-ſtone A and B, will take up a much larger Piece of Iron, than the naked Stone it ſelf will take up. But if we conſider, that a Load-ſtone thus armed will neither attract more Iron, nor at a greater Diſtance than it did before, we may be able to find out the Cauſe of ſo ſurpriſing an Effect: For this being ſo, it is eaſy to ſee, that the Increaſe of the Force which we find in an armed Load-ſtone, ariſes from hence, that the Iron which is lifted up by the Armour, touches it in more Points, than the Load-ſtone it ſelf touches it in: For, as was ſhown in the firſt Part of this Treatiſe, that natural Glue, by which Bodies are joined and faſtened together, and which hinders them from ſeparating, conſiſts in the Parts being at reſt, with reſpect to each other.

53. How an armed Load-stone may be hindred from having this Effect.

53. And this is confirmed from hence, that if the Armour of the Load-stone be rusty, that is, if the Order of its Parts be disturbed, so that it is not capable of such a Contact as it was before; or which is the same Thing, if we put a Piece of rusty Iron to it; or lastly, if we put a Body that is ever so thin, betwixt the Armour and the Iron that we would take up, as for Instance, a Piece of Paper, it will then lift up no more than if it were unarmed, whereas the Interposition of such Sort of Bodies does not at all alter the other surprising Effects of the naked Load-stone.

54. How it comes to pass that a weak Load-stone, will sometimes carry off a Piece of Iron from a stronger one.

54. This Observation about the Armour, furnishes us with the Solution of a very great Difficulty, which is, *That sometimes a weak Load-stone, upon touching a Piece of Iron, which is suspended upon another and much stronger Load-stone, will take it off thence and carry it along with it:* For it is reasonable to think that in this Case, the weaker Load-stone touches the Iron in more Parts than the stronger one does.

55. That the two Poles of contrary Vertue in two Load-stones, increase each other's Force.

55. To this we may add, that the stronger Load-stone does in some Measure increase the Vertue of the weaker one, because it sends forth a great deal more magnetick Matter to it, and helps to support the Iron that hangs upon it. And this is the Reason why the *South*-Pole, in all Load-stones, that have not some considerable Irregularity in them, will take up more Iron in these Northern Climates of the World, than the *North*-Pole; because the *South*-Pole may be assisted by the Vertue that comes from the *North*-Pole of the Earth, but the other Pole cannot.

56. Why a Whirligig will turn about longer when it hangs upon a Load-stone, than when it turns upon a Table.

56. Some People have been very much surprised to see that if a Brass *Whirligig*, whose Axis is made of Iron or Steel be turned round upon a Table, and then taken up by a Load-stone, it will keep turning much longer, than if it be left to move upon the Table; but this is easily accounted for: For we need only consider, that one Reason why the *Whirligig* does not continue to move on for ever, is because its Weight makes it to bear pretty hard against the Body it moves upon: But when it is suspended upon a Load-stone, then its Weight, which endeavours to pull it off, causes it scarcely or but slightly to touch the Surface of the Load-stone, so that it turns about with the greatest Ease that can be.

57. How a Whirligig supported in this manner

57. Whence we may conclude, that if we make use of a very strong Load-stone, to lift up a very light *Whirligig* with; because the Vortex of a Load-stone will attract

tract it much more strongly, than its own Weight would press it against a Table; it must cease to turn about a great deal sooner, than it would do if it turned upon a Table.

may turn about but a little while.

58. It may seem, that the Declination of the Load-stone, or of a Needle touched by the Load-stone, may in some Measure contradict what has been said concerning the Nature of this Stone: For, if it be true, that the magnetick Matter which makes a kind of Vortex about the Earth, moves from one Pole to the other, in the Plains of the Meridians, why should not the Needles point exactly *North* and *South*? And why do they deviate in such a manner, that the *South*-Pole, which ought to look towards the *North*, declines about a Degree towards the *West*? To which I answer, that the magnetick Matter which moves in the Air, would go exactly from *North* or *South*, or from *South* to *North*, if it was not some way to accommodate it self to the magnetick Matter which moves in the exteriour Earth; but it happens, that in this exteriour Earth, the magnetick Matter is sometimes obliged to turn out of the Way that it would go in by the general Cause; because it finds more convenient Passages in those Places where the Iron Mines are. And this is the Reason why the magnetick Matter which moves in the Air, does not always go in the Plains of the Meridians, and also why the Needles touched by the Load-stone, are thereby determined to decline as we find by Experience they do.

58. Of the Declination of the Load-stone, and why the Needle after it is touched, does not turn exactly to North *and* South.

59. Now in order to make Iron divert the magnetick Matter out of its usual Course, we need only place the Needle of a Compass at a certain Distance from a Load-stone, as we see the Needle CD in the Figure is placed with respect to the Load-stone whose Axis is AB. For so long as no other Iron comes near this Load-stone, the magnetick Matter which goes out of it, disposes the Needle to be very nearly parallel to the Axis AB; but if any Iron comes near it, as for Instance, a Knife which the Matter that comes out of the Pole B of the Load-stone passes through, to enter into the Pole D of the Needle, whilst that Matter which comes out at A enters at C as it did before, we shall then find a considerable Alteration in the Needle, for it will quit the Line CD in order to place it self in the Line EF.

59. An Experiment to try this Declination. Tab. XV. Fig. 4.

60. Why the Load-stone has not always the same Declination in the same Place on the Earth.

60. And because it is certain that there may be Iron-Mines generated in some Countries where there were none before, and those which were in other Countries may be worn out; therefore it may happen that the Needle may have different Declinations at different Times in the same Place. So that we need not be surprised, that they who mentioned its Declination, about a hundred Years ago, affirmed, that it was six Degrees towards the East at *Paris*, whereas by the most exact Observations that I have been able to make, I found it was hardly one Degree that way about thirty Years ago, and is now one Degree towards the *West*.

61. That all Iron Mines are not capable of making the Load-stone decline.

61. But it is to be observed, that in order for the Iron to make the magnetick Matter turn out of its Course, it is necessary that the Situation of its Parts should be such, that the Pores which are in the form of Screws, should continue on directly. And, since this Disposition is not to be found in all Mines, and there may be some, where the Parts of the Iron are confused, therefore the Iron in all Sorts of Mines is not proper to cause a Declination in the Load-stone, nor is it easily to be attracted by this Stone.

62. That a Load-stone reduced to Powder ought not to lift up Iron at all.

62. Having thus explained all the Properties of the Load-stone, it remains, that we show how it may lose these Properties, and be reduced to a common Stone. In order to apprehend rightly how this may be done, we must consider, that *that* which is peculiar in the Load-stone is the Shape and Structure of its Pores; wherefore we can no sooner imagine this Shape and Construction to be destroyed, but at the same Time we must think, that the Load-stone will cease to be any longer so, and will not at all differ from a common Stone. Now it is evident, that if a Load-stone be beaten in Pieces and reduced to a very fine Powder, the peculiar Disposition of its Parts will continue no longer, and therefore it is also evident, that it will be no longer capable of having those Properties which we so much admire in it.

63. An Experiment of the Truth of this, and of magnetick Plaisters.

63. And this is confirmed by Experience. For having caused several Pieces to be cut off from a very good Load-stone, in order to make it of a handsomer Shape than it was, I took the largest Piece, which would take up a considerable Piece of Iron, and beat it small, and put the Powder into a Rag, after which it would not take up the least Piece of Iron that can be. And this may serve to undeceive those who, because they see that a whole Load-stone draws Iron, imagine that if it be

beaten

beaten and made up into a Plaiſter, it will draw Iron out of a deep Wound: For they may learn from hence, that the diſunited Parts have not the ſame Properties which they had before they were ſeparated. And if Load-ſtones are found to be uſeful in Plaiſters, it muſt be for ſome other Reaſon than what they have imagined.

64. We may alſo foreſee, that Ruſt when it gets into the Load-ſtone muſt ſpoil the Shape and Conſtruction of its Pores; and therefore we may conclude that this Stone muſt loſe its Vertue by being ruſty.

64. That a Load-ſtone may loſe its Vertue by growing ruſty.

65. We may alſo foreſee further, that a violent Fire may do that in a few Hours, which Ruſt will take up ſeveral Years in doing; becauſe it makes an Alteration in the Load-ſtone very much like what we ſee it does in Wood when it turns it into a Coal: Wherefore a Load-ſtone held ſome time in the Fire muſt loſe all its Vertue.

65. That Fire deſtroys the Vertue of a Load-ſtone.

66. We may likewiſe add, that the Air when it is moſt dry and leaſt capable of ruſting the Load-ſtone, ought to diminiſh the Force of it; becauſe it reſiſts the Motion of the magnetick Matter, which is endeavouring to come out of the Load-ſtone, and forces it to find a Paſſage within it; in the ſame manner, as we before ſaid, that a great Part of that Matter which moves within the internal Earth, continues on its external Motion in the external Earth which ſurrounds it: And thus the Parts of the Load-ſtone which are near the Superficies become at laſt very different from what they were.

66. That the Air alone will alter a Load-ſtone.

67. Now when theſe external Parts are thus corrupted and ſpoiled, they are not at all different from a common Stone; and they hinder that Part within, which is ſound and entire, and which continues in the Form of a Load-ſtone, from coming ſo near the Iron, as it would do if they were gone: And this may be a Reaſon why a whole Stone, may not be able to lift up ſo much Iron as it would do if theſe corrupted Parts were taken away. And indeed, I my ſelf have ſeen a pretty large Load-ſtone which weighed thirteen Ounces, and which would hardly lift up an Ounce of Iron, after a good deal of it next the Superficies had been taken off all around, ſo that it weighed no more than five Ounces; take up two Ounces and a Half of Iron.

67. Why Part of a Load ſtone will ſometimes lift up more Iron than the whole Load-ſtone.

68. The only Remedy hitherto found to hinder the Air from thus corrupting the Load-ſtone, is to ſurround it with ſeveral Pieces of Iron; and this perfectly agrees with what was juſt now ſaid: For the Iron affording a freer

68. How the Iron preſerves the Vertue of the Load-ſtone.

a freer Passage to the magnetick Matter than the Air does, it bends it self and continues on its Course in the Metal, and therefore will not so soon make any Alteration in the Pores of the Load-stone.

69. How a Load-stone may lose its Vertue in a Moment, and recover it again afterwards.

69. In all the Effects of the Load-stone, the greatest Share of them is owing to the magnetick Matter; wherefore the Construction of its Pores would be wholly useless if there were none of this Matter. But it may so happen, that the large Quantity of this Matter which moves about a great Load-stone, may carry off that small Quantity, which makes a little Vortex about a small Load-stone which is near to it: And thus I have found by Experience, that a small Load-stone armed and set in a Ring, which would lift up two Ounces of Iron, lost all its Vertue in an Instant, by coming too near a very good Stone. However it recovered it again in two Days Time; which was doubtless owing to this, that the Air furnished it with magnetick Matter in the Room of that which it lost.

70. Of some Properties falsely ascribed to the Load-stone.

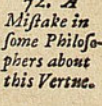
70. As to what some Writers have related, that a Load-stone will not attract Iron, [1] if there be a Diamond near, and that Onions and Garlick will make it lose its Vertue; these are contradicted by a thousand Experiments which I have tried. For I have shown, that this Stone will attract Iron through the very thickest Diamonds, and thro' a great many thick Skins which an Onion is made up of.

71. Of the attractive Vertue of Amber and several other Bodies.

71. Having at large explained the Properties of the Load-stone, and especially *that* by which it attracts Iron; I would not willingly neglect speaking of that Property taken Notice of in *Amber, Jet, Gum, Wax, Glass and most Jewels*, all which, when they are rubbed, will take up indifferently Chaff and such Sort of light Things. I am therefore of Opinion with some others that there is a certain Matter, which is very subtle, continually moving in the smallest Pores of these Bodies, and that it comes from the Center to the Superficies, where it is reflected inwards by the Resistance of the Air which it then meets with. Now when these Bodies are rubbed, this gives a sufficient Force to the Matter contained in them, to over-

1. *If there be a Diamond near, &c.*) "There is such a Disagreement betwixt a Diamond and a Load-stone, that if a Diamond be near, it will not suffer the Iron to be attracted; or if the Load-stone is put to it and takes hold of it, it will pull it away." *Pliny, Book* 37. *Chap.* 4.

overcome the Reſiſtance of the Air, and to extend it ſelf to a little Diſtance all round them; but becauſe it cannot go very far without loſing ſome of its Force; the Agitation and Circulation of the Air will drive it back and force it to turn and enter into ſome of the Pores which it came out of, and where other Matter cannot ſo conveniently enter, becauſe it is not ſo well proportioned to the Bigneſs and Figure of thoſe Pores. Thus in *Amber*, for Example, that has been rubbed, a great Number of the Particles of this Matter, like ſo many fine Threads, too ſmall to be ſeen, come out of it, and dart themſelves into the Air, where meeting with ſmall Bodies, they get into the Pores of them, and then return back into the *Amber*; at the ſame Time, the Air continually repelling theſe ſmall Threads, and forcing them to contract themſelves into leſs and leſs Compaſs, preſſes likewiſe in the ſame Manner upon the light Bodies into the Pores of which theſe ſmall Threads have thruſt themſelves; ſo that in returning back to the *Amber* they carry ſmall Straws, in whoſe Pores they are engaged along with them. All which is confirmed from hence, that we do not perceive the leaſt Degree of this Vertue in *Amber* or any other ſuch like Body if it be not excited by rubbing.


72. *A Miſtake in ſome Philoſophers about this Vertue.*

72. As to any Thing further; there is no Need of aſcribing any other Qualities to the Matter which comes out of theſe Bodies, in order for them to have the Vertue of attracting Straw and Chaff; as, that they muſt be greaſy in order to have Things ſtick to them; for beſides that the Power of ſticking is not at all explained, it is not in the leaſt probable that Glaſs or precious Stones, which have the ſame attractive Vertue which we find in *Amber*, have any Greaſineſs in them. For if we could think that there was any Thing of that Nature, in the Sand and Aſhes of which the Glaſs is made, it muſt all be conſumed by the Fire in which they are melted.



CHAP. IX.

Of Subterraneous Fires and Earthquakes.

1. That to explain the Nature of subterraneous Fires, is the same as to explain the Nature of all other Fires.

IN Order to explain what is most extraordinary in the Earth, it will be very proper to speak of *subterraneous Fires.* The dreadful Effects produced by them do too often excite our Admiration, not to endeavour to discover the Cause of them. The Fires which I here mean and intend to explain, are such as those which sometimes are seen to come out of Mount *Hecla* in *Island, Ætna* or Mount *Gibel* in *Sicily*, and *Vesuvius* in the Kingdom of *Naples*: And because there is no Manner of Difference betwixt these Fires, and those which we kindle in our Chimneys, it is evident that we cannot explain the Nature of the one, but we must at the same Time explain the Nature of the other. So that this Discourse will take in all that can be said of the Nature of Fire in general.

2. Of the Nature of Fire.

2. Now if we consider, that the principal Qualities of Fire, are Heat and Light, we shall be convinced that its Nature consists in nothing else but this; that Fire is nothing but a certain Collection of terrestrial Particles indifferently solid, which are all in a very great Agitation, because they swim about in the Matter of the first Element only, which they are of the same Rapidity with.

3. Why its Parts are moved so very quick.

3. In Order to have as clear a Notion of this as can be, we must remember, that the Velocity with which the Matter of the first Element moves, is incomparably greater than that with which the Parts of the second Element move, and that the small terrestrial Bodies which swim in a Mixture of these two Elements, can only move with the Velocity of the second Element, because this stops the violent Motion which the first Element would impress upon them: So that when these Bodies are surrounded with the Matter of the first Element only, they must necessarily be as rapid as that, in the same Manner as a Piece of Wood moves as quick as the Torrent it swims in.

4. Why it is hot and light.

4. This being supposed; and taking also for granted what has been said concerning Heat in the first Part of this Treatise; it is evident, that the actual Motion of the small Parts of terrestrial Bodies which are solid, is the true Cause of the Fire's being so *hot* as we feel it. And

if

if we call to mind what the Nature of Light was there ſaid to conſiſt in, we ſhall be convinced, that the Effort which all theſe terreſtrial Parts make to thruſt forward and drive off every Way round them the ſmall Globules of the ſecond Element, muſt cauſe [1] the Fire to be *luminous*.

5. How it is produced by a Flint-ſtone and a Steel.

5, And that the Parts which Fire is made up of, ſwim in the Matter of the firſt Element only, is what we ſhall be fully convinced of the Truth of, if we conſider how Fire is originally generated; that is, how it may be produced when there is none, either by ſtriking two Flints againſt one another, or rather by ſtriking a Flint-Stone againſt a Steel. If therefore we look upon the Figure and conſider, that the Parts of the Flint-ſtone A are ſo connected together, that there are ſmall Interſtices left betwixt them, which are filled with the Matter of the firſt and ſecond Element: Whence it is eaſy to ſee, that by the Stroke of the Flint-ſtone A againſt the Steel B, its Parts may get ſo near to one another, and the Interſtices between may become ſo ſmall, that they can contain only the Matter of the firſt Element; the Matter of the ſecond Element being driven out, and they then left full of the Matter of the firſt Element; Then, if we conſider, that the Parts of a Flint-ſtone are very ſtiff, it is eaſy to apprehend, that they are alſo ſpringy and have a Tendency to return back into the State which they were in before; which they do with an incredible Swiftneſs. And becauſe Bodies which have a reciprocal Motion backwards and forwards, always go a little beyond the Place, where they would be at reſt in their natural State; ſo likewiſe the Parts of the Flint are ſeparated a little further from each other than they were before it was ſtruck againſt the Steel, which cannot be, they being ſo very brittle, but that they muſt be entirely ſeparated from the Maſs of which they were Parts. They muſt therefore fly off into the Air, and be ſurrounded, for ſome Time at leaſt, as you ſee in C, with the Matter of the firſt Element: For being very ſolid, they have ſufficient Force to puſh back every Way the ſmall Globules of the ſecond Element, (which are continually endeavouring to get into the Places which they were driven out of,) by their rapid

Tab. XV. Fig. 5.

1. *The Fire to be luminous*) Concerning the true Cauſe of this Particular, and of the following Phænomena of Fire, See *the Notes on Part* I. *Chap.* 27. *Art.* 15.

rapid Circumrotation: And therefore [1] these little Pieces must appear *luminous.*

6. Why the Fire goes out for want of Fewel.

6. This being the Nature of Fire, it from hence follows, that it must go out in a Moment, if it be not supplied with Fewel; both because the small terrestrial Parts of which it is composed, by dashing one against another, are divided into still smaller Parts, which have not Force enough to resist the second Element, which is continually endeavouring to extinguish or choak it; and also because these same Particles, by driving forward the Globules of the second Element, move on all Sides out of those Places where they first were, and come in amongst the Parts of the Air, where they lose their Motion by communicating it to the Air, and so go away in Smoak.

7. The general Conditions of Bodies proper to nourish Fire.

7. Fewel therefore must of Necessity be added to Fire, if we would have it long preserved in the same Place; that is to say, some Body must be put so near to it, that the Parts of that Body may go into the Place of those which are dissipated by the Fire or which are converted into Smoak. And in order hereunto, it is necessary in the first Place that the Parts of this Body should be so disposed, that they may easily be separated successively from each other by the Action of the Fire which they are to feed: And that there should also be a sufficient Number of them to repell the Parts of the second Element, which are continually endeavouring to choak the Fire: This the Parts of the Air cannot do because they are too fine, wherefore Air is not sufficient to nourish Fire.

8. The particular Conditions.

8. The Conditions requisite in terrestrial Bodies to compleat these two general Properties, are first, that their Parts should be of unequal Bigness, so that the smallest of them being first agitated, may help to increase the Motion of the larger: *Secondly,* that the Pores of these Bodies should be large enough to admit the Parts of the third Element which are already on Fire, in order to put the Parts of these Bodies into Motion; And *Lastly,* that these Parts should be so connected with each other, that the Parts of the second Element will sooner be driven from them all round, than they entirely be separated from each other.

9. Every

1. *These little Pieces must appear luminous*) Mr. *Hook* observed with a Microscope, that the Particles of Steel being also melted into small Globes, or at least being red-hot shone, and kindled the Tinder. See *Hook's Micography, Observat.* 8.

9. Every one of these Conditions are to be found in all Sorts of dry Wood, with this Difference only, that they are in some in a greater, in others in a less Degree; wherefore they will all of them burn, but some more easily than others; for Example, that which has the largest Pores, or that in which all the forementioned Conditions are found, or some of them in the greatest Degree, will most easily burn.

9. Why Wood is easy to burn.

10. The first and the third of those Conditions now mentioned, are indeed to be found in Metals, but because they have not the second, they are not at all proper to nourish Fire; yet however, as the most solid Wood, or that which has the fewest Pores, will very easily burn when it is cut into Chips, or reduced to Shavings like those taken off by a Joyner's Plane; so likewise the Filings of Steel, thrown cross the Flame of a Candle, will burn immediately, and every Particle of it will become a very bright Spark.

10. Why Metals are not proper to nourish Fire.

11. The third of these Conditions seems to be wanting in such Liquors as Oils and *Aqua-Vitæ*, which yet are very easily converted into Fire. But it is to be observed, that these Sorts of Bodies being made up of ramous Parts, in which there are a great many little Corners that the Parts of the second Element cannot get into, they must contain a larger Quantity of the Matter of the first Element, than other combustible Bodies generally do: Now this Matter of the first Element, conspires with that of the Fire, to drive away the Globules of the second Element, and contributes to make the Parts of these Sorts of Liquors the more inflammable.

11. How some Liquors, such as Oils, serve to nourish Fire.

12. When I said that one Condition necessary to make a Body capable of nourishing Fire, was, that it must be porous (and its Pores must be filled with some Matter, because there is no *vacuum* in Nature;) I did not mean, that its Pores should be filled with such Matter as can hardly be driven out; for that is much the same Thing as if it had no Pores at all: Thus, green Wood, whose Pores are filled with a great Deal of Water, will scarce burn at all, in Comparison with dry Wood, out of which, the Air which gets into the Place possessed before by the Water, is very easily forced; and thus likewise, a Linnen Rag dipped in *Aqua-Vitæ*, when it is set on Fire will not be burnt, because the Fire which is nourish'd only by that Spirit has no more Force than is sufficient to lay hold of and carry away the Parts of the *Aqua-Vitæ*, so that it cannot agitate the Parts of the Rag, so long as it contains some other Bodies besides Air in its Pores.

12. Why green Wood is hard to burn.

13. Of Gunpowder.

13. If we consider the Ingredients of which [1] Gunpowder is made, we shall find that it has all the Conditions requisite to make a Body take Fire with the greatest Ease. It is a Composition of *Sulphur*, *Salt-Peter* and *Charcoal*, beaten together a good while in a Mortar, and now and then a little *Water in which Lime has been slacked*, poured upon it; This Mixture becomes a pretty hard Paste, which in passing through a Sieve, conforms it self to the Bigness of the Holes, and is divided into small Grains, which are afterwards dryed with great Care.

14. What the Nature of the Ingredients of which it is composed is.

14. Now *Sulphur*, is in its own Nature combustible, because it is oily: And if it does not so easily burn when it is in the Mass, the Reason is, because its Parts are then a little too much compressed, and besides not being very solid, they are not able to drive from them always the Matter of the second Element. The *Salt-Peter* is composed of very solid Parts, and which are of such a Figure as take up more Room when they are put in Agitation

1. *Gunpowder*) The Cause of the Explosion of Gunpowder is thus explained by the famous Sir *Isaac Newton*, 'When Gunpowder takes Fire, it goes away into flaming Smoke. For the Charcoal and Sulphur easily take Fire, and set fire to the Nitre, and the Spirit of the Nitre being thereby rarified into Vapour, rushes out with Explosion, much after the manner that the Vapour of Water rushes out of an *Æolipila*; the Sulphur also, being volatile, is converted into Vapour, and augments the Explosion. And the acid Vapour of the Sulphur, (namely that which distils *under a Bell* into Oil of Sulphur) entering violently into the fix'd Body of the Nitre, sets loose the Spirit of the Nitre, and excites a great *Fermentation*, whereby the Heat is farther augmented, and the fixed Body of the Nitre is also rarified into Fume, and the Explosion is thereby made more vehement and quick. For if Salt of *Tartar* be mixed with Gunpowder, and that Mixture be warmed till it takes Fire, the Explosion will be more violent and quick than that of Gunpowder alone; which cannot proceed from any other Cause than the Action of the Vapour of the Gunpowder upon the Salt of *Tartar*, whereby that Salt is rarified. The Explosion of Gunpowder arises therefore from the violent Action whereby all the Mixture, being quickly and vehemently heated, is rarified and converted into Fume and Vapour, which Vapour, by the Violence of that Action, becoming so hot as to shine, appears in the Form of Flame.' *Opticks, pag.* 317.

So likewise concerning *Aurum Fulminans* mentioned above, (*Part* I. *Chap.* 26. *Art.* 13.) the same excellent Person says, '*Pulvis Fulminans*, composed of Sulphur, Nitre and Salt of *Tartar*, goes off with a more sudden and violent Explosion than Gunpowder, the acid Spirits of the Sulphur and Nitre rushing towards one another, and towards the Salt of *Tartar*, with so great a Violence as by the Shock to turn the whole at once into Vapour and Flame. Where the Dissolution is slow, it makes a slow Ebullition and a gentle Heat; and where it is quicker, it makes a greater Ebullition with more Heat; and where it is done at once, the Ebullition is contracted into a sudden Blast or violent Explosion, with a Heat equal to that of Fire and Flame.' *Ibid. page* 353, 354.

gitation than when they are at Reſt, with reſpect to each other. And as to the *Charcoal*, we know that *that* is made of Wood extinguiſhed before it is quite burnt up, and muſt therefore contain a very great Number of Parts eaſily to be put in Motion, and alſo a very great Number of Pores. For beſides thoſe which were in the Wood before, there muſt be a great Number of others formed by the Fire. And as to the Lime-water, it is evident, that it ſerves, in the firſt Place, to hinder the other Ingredients from taking Fire, whilſt they are beating in the Mortar, and alſo to connect them a little together. But as the ſame Things may be done by a great many other Liquors, I don't ſee why this ſhould be uſed rather than any of them, except they who make Gunpowder find by Experience, that the Powder moiſtened by this grows ſooner dry, and is formed into harder Grains.

15. Why Gunpowder ſo eaſily takes fire.

15. Wherefore, this ſurpriſing Compoſition, which was firſt found out by Chance about three hundred Years ago, will very eaſily take fire; becauſe the Fire which is put to any ſmall Part of its Superficies enters in by Means of the Pores of the *Charcoal*, in a Moment of Time; and a great many Parts take fire almoſt all together; firſt thoſe of the *Charcoal* which are the eaſieſt of all to be put in Motion; and then thoſe of the Sulphur, which immediately agitate the Parts of the *Salt-Petre*, and theſe being very ſolid, and dilating themſelves very much, are the Cauſe of the extreme Violence of the Fire. The Powder being in Grains contributes alſo hereto, becauſe a great many of theſe Grains can take fire together.

16. What Flame is.

16. [1] *Flame* is nothing elſe but Fire wholly diſengaged from terreſtrial Bodies which yet are not altogether diſſolved, the Particles whereof being by the moſt vehement Agitation moved from their Place, and flying off, conſtitute a very rare, and conſequently very light, ſhining Body.

17. Why it appears of a Pyramidal Figure.

17. The Pyramidal or pointed Figure of Flame, is owing in the firſt Place to the Lightneſs of it, which by carrying it upwards, makes it open and divide the Air, which Opening muſt of Conſequence not be ſo wide at the

1. *Flame is nothing elſe*, &c.) *Is not Flame a Vapour, Fume, or Exhalation heated red-hot, that is, ſo hot as to ſhine? For Bodies do not flame without emitting a copious Fume, and this Fume burns in the Flame.* Newt. Opt. page 316.

the Place where it ends; and it is alſo owing to this, that the higheſt Parts of the Flame are not ſo ſolid, and are leſs agitated than the other, either becauſe they have been battered, and worn by daſhing againſt each other, or becauſe they have loſt a good deal of their Motion, for which Reaſon they are not ſo able wholly to reſiſt the ſecond Element which endeavours to compreſs them.

18. Of the Motion of the Air towards the Flame.

18. Becauſe the Parts of the Flame which are converted into Smoke have always ſome of the Matter of the firſt Element going along with them; therefore there muſt always be ſome other coming to the Flame from the Places about it to ſupply its Place; which cannot be, but the groſſer Parts of the Air muſt be alſo dragged along with it; and this is the Reaſon why the Air moves towards the Flame. And this Motion is ſtill increaſed from hence, that the Air is forced to go and fill up the Place of the Parts of the Wood which are converted into Fire.

19. That Flame contains in it ſome of the Matter of the ſecond Element.

19. The Matter of the firſt Element, which drags the Air along with it towards the Flame, cannot help dragging ſome of the Parts of the ſecond Element along with it alſo: Theſe therefore entering into the Flame along with the Matter of the firſt Element in which they ſwim, muſt of Conſequence be as much agitated as that, and ſo conſpire with it to drive away every Thing that endeavours to ſuffocate the Flame.

20. Why Bodies ſtruck one againſt another do not produce Sparks unleſs they be very hard.

20. I think I have not omitted any one conſiderable Circumſtance with reſpect to Fire in general: One Thing may here be demanded, and that is, How it comes to paſs, that if two Sticks be ſtruck one againſt another, as hard or harder than a Flint-ſtone is ſtruck againſt the Steel, we do not find any Sparks kindled: To which it may be anſwered; that the Reaſon is, becauſe the Wood being ſoft, the Parts which are ſtruck firſt approach a little ſooner to the ſecond than theſe do to the third, and ſo on: ſo that a very little only of the Matter of the ſecond Element is driven out of the Wood: Beſides the Parts of the Wood not being at all ſtiff, they return back very ſlowly into that State which they were in before they were ſtruck: Wherefore they don't break quite off, but give an Opportunity to the Globules of the ſecond Element to enter again into the Pores out of which they were forced: Whence it follows, that the Matter of the firſt Element cannot looſen the Parts of the Wood, nor put them into a ſufficient Agitation for them to be in the Form of Fire.

21. This

21. This is confirmed from hence, that if two Sticks of exceeding hard Wood be ſtruck one againſt another, they will produce Sparks of Fire, in the ſame Manner as two Flints ſtruck one againſt another. So likewiſe, if two Pieces of ſoft Wood be rubbed one againſt another for ſome Time, ſo that a good deal of the Matter of the ſecond Element is perpetually made to come out of them, and the Parts of the Wood put into a more than ordinary Agitation, they will not only ſend forth Sparks of Fire, but many Times be all of a Flame.

21. How rubbing two Bodies which are not hard, one againſt another, will make them burn.

22. We might alledge for an Inſtance of the Truth of this, what is ſaid concerning certain People in *America*, who have no other Way but this to kindle a Fire when they want one; but not to go ſo far, don't we ſee every Day that the Axle-tree of a Coach, when it goes very quick in dry Weather, and the Nave of the Wheel, by their mutual Attrition will both be ſet on Fire?

22. Inſtances of this.

23. After what has been now ſaid concerning Fire in general, there is no great Need of ſaying any Thing particular concerning *ſubterraneous Fires.* For it is eaſy to apprehend, that where there are Mines of *Sulphur* or *Bitumen*, they muſt ſend up Exhalations, which meeting with ſubterraneous Caverns, they muſt ſtick to the Arches of them, in the ſame manner as *Soot* does in our Chimneys, or as Flower of Sulphur does on the Tops of the Chymiſts ſubliming Veſſels, where they often mix themſelves with the Nitre or Saltpeter, which comes out of thoſe Arches in like manner as we ſee it come out at the Bottom of an old Wall, and ſo it makes a kind of Cruſt which will very eaſily take fire.

23. Of the Matter of ſubterraneous Fires.

24. There are ſeveral Ways by which this Cruſt may take fire; one is, the Daſhing together of ſome of its Parts which are forced by their own Weight to ſeparate from the Arch of the Cavern where this Cruſt is formed; another is, the Fall of ſome great Stone, which is undermined by inſenſible Degrees [1] by the Rain till it be quite looſened from the Rock which is over this Ca-

24. Several Ways of their taking fire.

1. *By the Rain*, &c.) 'It is 'not only probable that Stones are 'broken off by their own Weight, 'but becauſe Rivers run over them, 'the continual Moiſture weakens the 'Joints of the Stone, and is every 'Day getting it off from thoſe which 'it is faſtened to, and (as I may ſay) 'ſhaving off the Skin in which it is 'contained. Afterwards by perpetual wearing they grow leſs and 'leſs, and in length of Time become ſo weak, that they are no 'longer able to bear their own 'Weight. Then Stones of a prodigious Weight fall down, and 'thoſe Rocks tumble, &c.' *Seneca, Nat. Quæſt. Book 6. Chap. 21.*

vern, and so tumble down, and breaking in Pieces some part of this Crust, it sets it on Fire in the same manner as we said the *Americans*, set two Pieces of Wood on Fire, by rubbing them one against another; or as the Pestles in the Gunpowder-Mills sometimes set the Powder on Fire in pounding it, if the Materials shall chance to be but a little too dry: A third is, when one Stone as it falls strikes against another, and so produces some Sparks which set fire to the combustible Matter, that is near; to which we may add farther, that a large Stone, in falling from a very great Heighth in these subterraneous Caverns, may by the Swiftness of its Fall, force the Air (which it meets with, and which it causes to ascend,) to move so extremely swift, as to put some parts of the terrestrial Matter which are there, in as great Agitation as the Matter of the first Element, and which may consequently [2] set on Fire all such combustible Things as are in the Way.

25. That there are subterraneous Fires which do not appear.

25. All the subterraneous Fires which are kindled in the Bowels of the Earth, do not always break out so as to be seen; for they may be immediately choaked as soon as they begin, for want of Vents or Holes for the Fumes to exhale through: So that those People who live upon the Earth under which such Fires are kindled, may not always perceive them.

26. How Earthquakes are caused.

26. However, if the subterraneous Cavern be filled with a very dense Exhalation, such as that which a Candle sends forth when it is just put out, it may take fire all at once, and by dilating it self, lift up the Earth which is above it, in the same manner as Gunpowder put into Mines lifts up the Ground under which those Mines are made. After which, when the Exhalation is spent, the Earth which is lifted up, falls down again by its own Weight; and in this manner are Earthquakes effected; it may also happen, that one such Earthquake may be succeeded by several others, if there be several Caverns near one another, which have any Communication with each other, so that the Exhalations they are filled with may be successively kindled.

27. It

2. *Set on fire*, &c.) A much more probable Cause of the setting on fire than any of these, is such a *Fermentation* of Vapours as that of some Liquors, and of what they call *Pulvis Fulminans*. See *above Art.* 13.

27. It may so happen, that a single Cavern may be so large, and the Tract of Land which is as an Arch over it, may be so great, that it may divide assunder and open towards the Middle, and the Places thereabouts may sink down much deeper than they were before: And this explains how whole Towns may be swallowed up by one single Earthquake.

27. How whole Towns may be swallowed up.

CHAP. X.

Of FOUNTAINS.

THOUGH we cannot consider the Origin of Fountains without some Kind of Admiration; yet the Enquiry into this Origin, does not seem to be any very difficult Thing. For first, if we consider, that the Springs of most of them never dry up, and that the Rivers, which are a Collection of them, though they run continually into the Sea, yet never swell it, we may easily conclude, that the Sea furnishes all the Fountains with Water.

1. That the VVaters of Fountains come from the Sea.

2. Moreover, seeing 'tis manifest that there are a great Number of Chinks in the outward Earth, it is reasonable to think, that these [1] are like so many Channels through which the Water is carried from the Ocean, by its own Weight and Liquidness to the most remote Places where we observe the Springs to be. But because heavy Liquors contained in large Vessels, keep themselves upon a Level, and do not rise higher in one Place than in another; we don't see how the Water which comes from the Sea should

2. How this VVater gets to the Fountains.

1. *Are like so many Channels*, &c.) To which we may add, that Rain and melted Snow, and Vapours raised out of the Sea by the Heat of the Sun, and driven by the Winds upon the cold Sides of very high Mountains, on which they stick, being condensed by the Cold, and run through the Chinks of the Earth and Stones, into Receptacles of Clay and Stones which are within it; increase these Waters by being added to them; or rather that they make up the principal Part, if not quite the whole of them. See *Varen. Geogr. Book* I. *Chap.* 16. *Prop.* 5. *Clerc's Phys. Book* II. *Chap.* 7. *Voss. of the Orig. of the* Nile *and other Rivers. Chap.* V *and* VIII. *and the Philosophical Transactions, Numb.* 119, *and* 192.

ſhould riſe higher in *Burgundy*, for Example, or *Champaign*, where the Springs of the River *Sein* are, than in the Sea near *Havre-de-grace* where this River diſcharges it ſelf. And yet the Countries of *Burgundy* and *Champaign*, where theſe Springs are, being ſo much higher than the Surface of the Sea, as the whole Fall of the River *Sein* in the whole Length of its Courſe is, we muſt conclude that the ſmall Veins of Water, which reach to the Places where theſe Springs are and furniſhes them with Water, muſt riſe ſo much above the Surface of the Sea. Wherefore we muſt find out the Cauſe of the Waters being raiſed to the hollow Places in the Mountains from whence we ſee them come, and alſo explain why, when the Water in the Sea is ſalt, that in theſe Springs is not ſo.

3. That the Mountains do not draw up the Waters by Suction.

3. We cannot acquieſce in the Opinion of ſome Philoſophers, who aſcribe to the Parts of the Earth which are above the Veins of Water, a Power of ſucking and drawing them up to the Tops of high Mountains; becauſe we are ſure that Suction preſuppoſes a Power of moving it ſelf in the Body that ſucks. Thus we cannot ſuck up any Liquor without ſwelling our Bodies, which we ought not to preſume that the Earth can do; and the Compariſon they bring of a Sponge dipped into a little Water, ſignifies nothing: For, beſides that there can be but a little Water raiſed up in that Manner, it would follow, that the Water in the Springs would be ſalt, becauſe Salt can very eaſily paſs through all thoſe Places where any conſiderable Quantity of Water can paſs.

4. An abſurd Opinion of ſome Philoſophers.

4. Nothing can be more abſurd than the Opinion of ſome other Philoſophers, who are perſuaded that the Water of the Sea extends it ſelf to thoſe Places, in the higheſt Mountains, where we find any Springs, becauſe the Surface of the Sea is higher ſtill than thoſe Places in the Mountains: For if this were ſo, it would follow, that the Rivers which return into the Sea would aſcend and not deſcend.

5. That the Water of the Sea, aſcends in the Form of Vapours up into the Cavities of Mountains.

5. That then which appears to me moſt reaſonable to think concerning the Manner in which Water is raiſed, from thoſe very low Places, and which are at ſuch a Diſtance from the Sea, to which their own Weight and Liquidneſs brought them firſt, is this; that it is diſſolved into Vapours by the Heat which is in the Bowels of the Earth, which Heat is found by Experience to be the greater,

er, the deeper we go: Now these Vapours cannot extend themselves, nor continue on their Motion conveniently by expanding sideways, because there are others which endeavour to dilate themselves at the same Time on all Sides; wherefore they must necessarily rise up into the high Mountains: And this is so true, that some of them are carried up into the Air, where they are afterwards formed into, and compose Rain, Snow, and Hail.

6. This being so; It is easy to apprehend, that these Vapours, when they come towards the Superficies of the Earth, where the Parts of it are cold, must lose a great deal of their Motion: So that not having Motion enough to rise any higher, there remains only so much as is sufficient to make them slide by each other, and gather into small Drops of Water, whose Weight makes them run downwards; where a great many of them happening to meet together, they compose a small Stream of Water, which runs on further to some Place where it unites it self with a great many other such like Streams; And thus they all of them together compose a pretty large Vein of Water, which finding some Cleft in the Mountain for it to come out at; we call it a Spring of running Water or a *Fountain*

6. That these Vapours by being condensed, supply the Springs with Water.

7. The Veins of Water which thus supply the Springs or Fountains, ought to be found in the Cavities of Mountains, that they may come out and run down by their own Weight: And as for those, which in great Numbers lie hid under Plains and Valleys, it is evident that they can never rise from under the Surface of the Earth: However, these are not wholly useless; For besides their Usefulness in moisting some Parts of the Earth, and affording nutricious Juice for Plants, they serve also to form Wells and to fill them.

7. That they also furnish the Wells with Water.

8. And because the [1] Salt does not rise up in Vapours along with the Parts of fresh Water; it is manifest that the Waters of Springs and Wells must be fresh.

8. That both Spring and Well-Water ought to be fresh.

9. Wherefore, if there be any Springs which send forth *Salt Water*, as there are some in *Burgundy* and *Lorrain*, it is because they [2] dissolve the Salt which they meet with in the Earth as they run along; as we shall easily be convinced, if we observe that these Waters eat up their Banks by

9. How some Springs may send forth Salt-Water.

1. *The Salt does not rise up*, &c.) We may add, that the Salt is gradually separated from the Water by being strained through a great deal of Sand, and perhaps being mixed with other Salts, *&c.* as it passes through the Earth, is precipitated.

2. *Dissolve the Salt which they meet with*, &c.) See *Varenius Geograph. Book* I. *Chap.* 17. *Prop.* 14.

by Degrees, so that they are now much deeper than they formerly were.

10. Wherein the Vertue of medicinal Waters consists.

10. If instead of Salt, the Veins of fresh Water meet with any metallick Matter or any Minerals whatsoever, they take off some of the finest Parts from them; and hence arises all the different Properties of those Waters which have their particular Uses in Physick, such as those of *Forge*, St. *Mion*, *Pougues* and *Spaw*.

11. Of the Bourbon *Waters.*

11. The Waters of *Bourbon* are very [1] remarkable for their *Heat*, which very probably is owing to their being mixed with some small Bodies that are in great Agitation, which in some Measure resemble those small Parts which rise up first in Wine when it is distilled, and which Chymists call *Spirits:* For if these Waters be carried away, they immediately lose all their Vertue, if the Vessels they are put into be not well stopped.

12. That these Sort of Waters need not contain any sensible Quantity of those foreign Bodies.

12. And it is not at all necessary, that all these particular Sorts of Water, should contain any sensible Quantity of those foreign Corpuscles, in Order for them to have those Properties which we see in them. For we find by Experience, that *Regulus of Antimony* infused several Times in a large Quantity of Wine, will not be at all diminished, though it makes the Wine a very strong *Vomit*. A great many Physicians therefore do in vain perplex themselves, to find out by Distillations what those foreign Bodies are which are contained in medicinal Waters.

13. Of petrifying Springs.

13. The Vertue ascribed to some Fountains, [2] of petrifying, or turning into Stone, several Sorts of hard Bodies thrown into them, such as Pieces of Wood, Bones, and Mushrooms, consists in nothing else but this, that they con-

1. *Remarkable for their Heat*, &c.) See *Seneca's Nat. Quest. Book* III. *Chap.* 24. and Varen. Geogr. Book I. Chap. 17. Prop. 7.

2. *Of petrifying or turning into Stone*, &c.) *There is a River in* Thrace, *which if you drink of, it will turn your Bowels into Stone, and cases with Marble whatever is put into it.* Concerning which *Seneca* thus speaks, in his *Nat. Quæst. Book* III. *Chap.* 20. ' The Mud of " it is of that Nature, that it glues " Bodies together, and hardens them. " As the Dust of *Puteoli*, if it touch- " es the Water, it becomes Stone, " so on the contrary, this Water, " if it touches any Thing solid, sticks " and cleaves to it. Hence it is, " that Things thrown into this Lake " are afterwards taken out converted " into Stones. The same Thing " happens in some Parts of *Italy*, " if you put in a Rod or a green Leaf, " in a few Days after, you take out " a Stone —— And *Pliny*, *Book* II. *Chap.* 103. " In the *Cicons* Ri- " ver, and in the Lake of *Velinus*, " in the Country of *Marca di Ancona* Wood cast in, is covered o- " ver with a stony Bark, and in " *Surius*, a River in *Colchis*; so that " a hard Bark commonly covers o- " ver the Stone still. So likewise " in the River *Silarius*, beyond *Surrentum*, not only Rods put in, but " also Leaves turn into Stone; The " Water is otherwise very whole- " some to drink. "

contain in them, a great deal of that terreſtrial Matter, which we before ſaid helps to unite the more groſs Particles of Sand, and ſo compoſe Flint-ſtone, Free-ſtone, and Marble, a viſible Quantity of which is found [1] in the Tubes which bring the Waters of *Arcuil* and *Iſſi* to † this City; which Matter is ſtopped in the Pores of thoſe Bodies ſo that they are filled with it. And of this we have an undoubted Proof, becauſe the Bodies thus petrified appear no longer porous, but are much harder and heavier than they were before.

† *Paris.*

14. Of the Springs of Oil.

13. If inſtead of that terreſtrial Matter now mentioned, raiſed up by the Heat of the Earth in the Form of Exhalations along with a very great Quantity of Vapours, this ſame Heat ſhould raiſe up a conſiderable Quantity of greaſy Exhalations, which might come to unite together and condenſe, when they meet with the cold Parts of a Mountain, theſe would compoſe alſo a greaſy Liquor, and conſequently we ſhould ſee [2] a Spring running with *Oil.* But this can happen but very ſeldom, becauſe ſuch Exhalations are much harder to be raiſed up than Water. And if there be any little Veins of Oil to be met with at all, it muſt be in very low Places ſuch as Mines are.

15. Of a very wonderful Fountain.

15. There are other Springs which are remarkable, not for any particular Vertue that is in their Water, but only becauſe [3] the Water runs at a certain Time, and keeps a certain Period: For theſe Springs are obſerved to run when the Sea flows, and to ſtop when the Sea ebbs. It will be no difficult Matter to account for this, if we conſider that all the Way from

1. *In the Tubes,* &c.) ‘ A whitiſh ‘ and commonly ſulphuriſh Water, ‘ hardens about the Canals and ‘ Tubes.’ *Seneca*'s *Nat. Quæſt. Book* III. *Chap.* 20. ‘ The Springs ‘ at *Marpurg* beyond the *Rhine* in ‘ *Germany* are hot, and their Waters ‘ make a Pumice-ſtone about the ‘ Banks.’ *Pliny, Book* 31. *ch.* 5.

2. *A Spring running with Oil,* &c.) *Polyclytus* relates, ‘ That near ‘ *Soli,* a City of *Cilicia,* there was a ‘ ſpring that ſupplied the Place of ‘ Oil. ---- *Theophraſtus* ſays, that ‘ there was a Spring in *Æthiopia,* ‘ which had the ſame Vertue. That ‘ the Water of the Spring *Lycos* would ‘ burn by putting a Candle to it; and ‘ the ſame is reported of *Ecbatana. Plin. Book* 31. *Chap.* 2. Some ſuch Sort of Springs are now to be found alſo. See *Varen. Geogr. Book* I. *Chap.* 17. *Prop.* 8.

3. *The Water runs at a certain Time,* &c.) ‘ There is a Spring in ‘ the Form of a Well near the Tem- ‘ ple of *Hercules* at *Cadiz,* which ‘ ſometimes riſes and falls as the Sea ‘ does; at other Times it does the ‘ reverſe; in the ſame Place another ‘ agrees with the Times of the Sea.’ *Pliny Book* II. *Chap.* 97. There are ſome Springs now to be found which do the ſame. See *Varen. Geogr. Book* I. *Chap.* 17. *Prop.* 17.

from the Sea to the Mountain where any one of these extraordinary Springs is, there is a Channel, into which the Water of the Sea enters but a little, the remaining Part of it being filled with Air only, because it is above the Level of the Sea: This being supposed; every Time the Sea flows, it rises up in this Channel and fills it fuller than ordinary: And as it rises, it drives along the Air and Vapours contained therein towards the Head of the Spring: Whence consequently the Water must run out. On the other Hand, when the Sea ebbs, the Water in the Channel descends, and the Air also that is in it returns towards the Sea, and carries along with it, all the Vapours that could be condensed into Water; So that the Spring is dry all that Time.

CHAP. XI.

Of WINDS.

1. Of the Words Wind.

HAVING thus endeavoured to give an Account of what is most considerable in the Earth; let us now examine what passes in the Air, and try to explain what are generally called *Meteors*, the most common of which is the *Wind*, that is to say, that sensible Agitation of the Air by which a considerable Part of it is carried out of one Country into another.

2. That the Wind ought to blow continually from East to West in the torrid Zone.

2. Now if we consider that the fluid Matter of the first and second Element which turns round about a certain Center, describes an entire Circle so much the sooner as the Circle is less; for Instance, that which turns about the Sun, and is near it, makes a Revolution sooner than that which is further off; and that which is about *Jupiter*, and very near him, compleats its Course sooner than that which is more distant; we shall be apt to think that the Case is the same with respect to the Matter of the first and second Element which encompasses the Earth, and turns about it; and consequently it should seem that [1] the fluid Matter which is about the Equinoctial Line, should

1. *The fluid Matter which is about the Equinoctial*, &c. To this we may add, that the Sun, in all Parts of the torrid Zone very much rarifies the

ſhould take up a little more Time to finiſh its Revolution from *Weſt* to *Eaſt*, than that Matter which is about the two Poles, where the Circles deſcribed by it are the leaſt of all: And becauſe the Earth is always carried that Way by this Matter, we conclude, that it muſt be carried with a mean Velocity betwixt that of the Matter which is near the Poles, and that of the Matter which is near the Equator; that is to ſay, it advances not quite ſo faſt from *Weſt* to *Eaſt*, as the Matter which is near the Poles does, and a little faſter than the Matter under the Equator; where conſequently we ought to perceive a Wind from *Eaſt* to *Weſt*: And this is what all Mariners have found by Experience; who have always obſerved the Wind on their Backs when they ſail from *Eaſt* or *Weſt* in the torrid Zone, and alway the contrary Wind when they ſail from *Weſt* to *Eaſt*.

3. Of the Qualities of the Wind.

3. Becauſe the Air becomes of the ſame Nature with the Country through which it paſſes, and is very much heated in going over ſandy Places, which reflect almoſt all the Rays of the Sun; and very much cooled, in paſſing over Water, which abſords almoſt all the Rays; it will eaſily appear, that the Wind which we are ſpeaking of, muſt conſiderably cool thoſe Countries into which it is carried over a long Tract of Sea. And thus we apprehend the *Eaſtern* Parts of *Africa* to be very temperate, though they be the Middle of the torrid Zone, becauſe they are perpetually cooled by the *Eaſt* Wind which comes thither from the *Perſian* Sea: But it is otherwiſe in the *Weſtern* Parts; for though the *Eaſt* Wind prevail there as it does in the other Countries, yet it does not come thither till it has had Time to be heated in paſſing over a great many ſandy Countries.

4. The

the Air which it is every Day almoſt directly over; and the Air thus rarified, becauſe when the Sun is about ſetting, it cannot take up ſo much Space, muſt neceſſarily be condenſed by the Force of the denſer and heavier Air ruſhing upon it from the *Eaſt*. Wherefore the whole Maſs of Air muſt conſtantly follow the Sun, that is, flow towards the *Weſt*. See *Clerc's Phyſick*, *Book* III. *Chap.* 5. *and the Philoſophical Tranſactions, Number* 183.

But concerning the Wind's blowing from the *Eaſt* in the torrid Zone, *Ariſtotle* ſays, *And ſo here the* North-*Wind ceaſes and cannot penetrate any farther; upon the* Southern *Coaſt beyond* Lybia, *as the Wind blows* North *and* South *here, ſo there the* Eaſt *and* Weſt *Wind always blow ſucceſſively by turns.* Meteor. 2. Chap. 5. *It is a very wonderful Thing* (ſays *Fred. Bonaventure*) *that the oldeſt Philoſophers, when neither he nor any of the Antients, as we believe, had found out what thoſe Countries were, ſhould yet ſo truly and ſo exactly declare what Winds did blow and what did not, in thoſe Places where they had never been.*

4. Why the East-*Wind blows in the Morning.*

4. The Sun cannot but dilate the Air by heating it, and so cause it to move sometimes one Way and sometimes another in the same Country, according to its different Position with respect to that Country; and this is the Reason why we perceive several Sorts of Winds. Thus for Instance, when the Sun rises with us, it dilates the Air which it is perpendicularly over, and causes it so to move every Way, that some Parts of it must come towards the *West*, where we are; Whence it follows, that we ought then to feel the Wind from the *East*.

5. Why the West-*Wind blows in the Evening.*

5. On the contrary, when the Sun sets, the Air which is directly under it, by dilating it self every Way, must have some Part of it come towards the *East*, where we then are with Respect to the Sun; Wherefore we ought to perceive the Wind to be *West* then. And because what we have said of our Country, may be applied to others which are out of the torrid Zone, we may assure our selves, that the *East* Wind blows in those Places in the Morning and the *West*-Wind in the Evening.

6. Why the Wind is North *at Noon-day.*

6. Further; It is to be observed, that when the Sun dilates the Air which is directly under it when it is in the Meridian, part of that Air must be lifted high up, and then carried by its own Weight towards that Pole which is next it, where it drives forward the Air that it meets with, and forces it downwards towards the Equinoctial Circle: Thus it is evident, that at Noon-Time, in any *Northern* Country, we ought to feel the Wind blow from *North* to *South*, and also to blow downwards.

7. Why the South-*Wind blows at Midnight.*

7. Without Doubt the Sun has no Power over those Countries where it is Midnight; yet because the Heat which it excites in the Day, continues for some Time on the Earth, this causes a large Quantity of Vapours to rise up which are hindred from ascending very high by the Air which the cold Night condenses; so that they are forced to move along upon the Earth from the Equinoctial Circle where they ascend in very great Quantities; and so carrying the Air along with them, they cause a Wind from *South* to *North*, in those Places which are on this Side of the Equator.

8. That the East-*Wind ought to be stronger than the* West-*Wind.*

8. These four Winds which blow in their Turns, from the four principal Quarters of the World, ought to have different Properties. And, First, the *East-Wind*, which prevails in the Morning, ought to be stronger than the *West-Wind*; not only because it conspires with the first general Wind which is observed to blow continually between the two Tropicks, but also because the Air which

dilates

dilates it ſelf and blows towards the *Weſt*, tends towards a Place where the Sun having been gone from the Meridian eighteen Hours, the Air has had Time to grow cool, and to be conſiderably more condenſed than that towards which the *Weſt-Wind* tends, where the Sun is but ſix Hours from the Meridian, and where it cauſes the greateſt Heat and the greateſt Rarefaction.

9. The *North-Wind* ought to be pretty ſtrong, becauſe it is excited by the Sun when it has the moſt Power, *viz.* when it is in the Meridian. And on the contrary the *South-Wind* ought to be very gentle.

9. That the North-*Wind ought to be ſtronger than the* South *Wind.*

10. As to any other Qualities of theſe four Winds, thoſe that are *ſtrongeſt* ought to be the *coldeſt*, according to what was ſaid concerning Cold in the firſt Part of this Treatiſe.

10. That the ſtrongeſt Winds ought to be the coldeſt.

11. Further, it is evident that theſe *ſtrong* Winds ought alſo to be the moſt capable of *drying*, that is, of diſlodging any Particles of Water which may be in the Pores or upon the Surface of terreſtrial Bodies which are expoſed to the Air; ſo likewiſe on the other Hand, the *gentleſt* Winds ought to be the *moiſteſt*, not only becauſe they cannot give the Parts of the Air a ſufficient Force to diſlodge the Parts of the Water which they meet with; but alſo becauſe the Vapours which are in the Air, not being in any Agitation, eaſily ſtick to any Bodies which come in their Way. There is a particular Reaſon why the *Weſt-Wind* ſhould be *moiſt*, and that is, becauſe it moves contrary to the general Courſe of the Air, which is from *Eaſt* to *Weſt*, and which cauſes the Vapours which ſorround the Earth to have a Tendency to move the ſame Way, and ſo makes them gather together on an Heap, and conſequently makes them more capable of *moiſtning* any Thing.

11. That they ought alſo to be the dryeſt.

12. It is true, that what has been ſaid upon the Subject of the fore-mentioned four principal Winds, ought not to be found exactly true any where but in the Middle of large Seas, where there is nothing to hinder the general Cauſe from producing its Effect; For as to any other Places, there are ſo many particular Cauſes which contribute towards the Production of Winds, that we ought not to wonder that they are ſo very irregular, and that we do not obſerve them in the Order now deſcribed.

12. That particular Cauſes may hinder theſe four Winds from being regular.

13. It is probable that *Ariſtotle* never thought of the general Cauſes of Winds, becauſe he makes no Mention of them in his Writings, but confines himſelf to particular

13. Ariſtotle's *Opinion about the particular Cauſes of Wind.*

cular Caufes only. And becaufe he obferved that Winds have the Property of drying, therefore he thought, that when the Wind blew, the Air was then moved along by a Principle which had no Moifture in it; fo that he afferts, that Winds are caufed by certain dry Exhalations, which arifing out of the Earth, move one particular Way upon the Superficies of it.

14. That Exhalations are not fo much the Caufe of Wind as Vapours are.

14. I do not deny but that the Exhalations which rife up into the Air and take their Courfe one particular Way, may help to carry the Air from one Country to another, and fo caufe that Agitation which we call Wind. But becaufe both Reafon and Experience convince us, that the fame Caufe which difpofes fome terreftrial Parts to exhale in this Manner, muft alfo at the fame Time excite a much larger Quantity of Vapours; and becaufe the Water which is converted into Vapours dilates it felf a great deal more than the terreftrial Parts which are in the Form of Exhalations can do; it cannot be doubted but that Vapours are the principal Caufe, and contribute much more to the Production of Winds, than Exhalations do.

15. That Vapours do not hinder Winds from having the Property of drying.

15. The Reafon why *Ariftotle* was not of this Opinion makes nothing againft me: For though the Winds are caufed chiefly by Vapours, yet they ought notwithftanding that to have as much the Property of *drying* as if they proceeded wholly from Exhalations; becaufe the great Agitation which the Particles of the Air and Water are in, makes them carry off a great many more Particles from a moift Body than thofe new ones which they leave upon it.

16. That there is no Wind but what is moift.

16. Nor is it to be doubted but that the Winds do fix fome new Particles, and that there is no Wind how violent foever, but does fomewhat moiften a Body that is perfectly dry: For we find by Experience, that if we dry a Linnen Cloth before the Fire, till it will fmoak no longer, fo that all the Moifture is gone out of it, and then expofe it a little while in the Wind, it will not be fo dry as it was before, but if it be held to the Fire, it will fmoak again.

17. What has been faid about Winds is confirmed by Experience in an Æolipile.
Tab. XV. Fig. 6.

17. What has been faid concerning Winds is confirmed by Experience in an *Æolipile*, which is a Veffel made of Copper or any other Metal of the Shape defcribed in the Figure. The Cavity of it is at firft full of Air only which is made to dilate it felf, by putting it near the Fire till the far greateft Part gets out at the Hole A; then the fmall Neck A is dipped into a Veffel of Water; and as the Air in the *Æolipile* condenfes by growing cold, the Water enters in, in the fame manner as we formerly faid the common *Thermometer* was filled with *Aqua-Fortis*.

This

This being done, the *Æolipile* is placed in the Situation you ſee in the Figure, and the low Part DEF reſting upon ſome red-hot Coals, the Water contained in it, riſes gradually in Vapours, which fly about in the Space DCBF, and daſh againſt one another, and make thoſe which they meet with near the Hole A to come out there with a great Force: Theſe Vapours carrying the Air along with them, produce a Wind, which continues till all the Water is evaporated or the Fire goes out; and this Wind has all the Properties which we obſerve in thoſe which we take Notice of upon the Surface of the Earth.

18. A Compariſon betwixt the Mountains and an Æolipile.

18. We may compare the Cavities of Mountains to the Hollow of an *Æolipile*; the Heat which is in the Bowels of the Earth to the Fire which dilates the Water in this Veſſel; the Water carried by the Sea in ſeveral ſubterraneous Channels, to the Water contained in it: and the Chinks of the Earth, through which the Vapours get, to the Hole of the *Æolipile*. But becauſe the Smallneſs of this Hole contributes to make the Vapours come out with ſo great Force; and becauſe it is very probable that the Chinks of the Earth are not ſo ſmall, or at leaſt, that the great Number of them is equivalent to one large Hole; therefore it is very difficult to believe that the Winds ſhould be ſo violent as they are ſometimes, if ſome other Circumſtances did not contribute to their Violence. Now it is certain [1] that there are Mountains ſo ranged, that they will not ſuffer the Vapours which come out of the Sides to take their Courſe but one particular Way only, and this muſt make them go with great Violence and Swiftneſs.

19. That Winds may be generated in Places where there are no Mountains at all.

19. And if there be a large Extent of Country in which there are no Mountains, there may notwithſtanding that be Winds generated, becauſe the Vapours which move upwards at firſt, may be determined by proper Miſts or Clouds to alter their Courſe and to move ſideways afterwards.

20. We

1. *That there are Mountains ſo ranged,* &c.) "Whatever is ſent "forth from Moors and Rivers "(which is a great deal and continu-"ally aſcending) in the Day-Time "is Fewel for the Sun; in the "Night-Time it is not conſumed, "but is contained between the "Mountains, and kept in a particu-"lar Place; When this is full and "will hold no more, but is preſſed "on one Side and ſo goes along "one particular Way; this is a "Wind. Wherefore it preſſes that "Way where there is a freer Paſ-"ſage for it, and more Room for "that which is heaped together to "run into. *Seneca's natural Quæſt.*

20. Why Winds from the Sea generally prevail in the Day, and those from the Land in the Night.

20. We may add to this, that an equal Quantity of Vapours is not raised every where alike in this Globe which is composed of Earth and Water; and that those which arise out of the moistest Places, being much greater in Quantity than those which rise out of other Places, have more Power to dilate themselves and to go towards those Places which are dry. And this is the Reason why when the Sun heats the whole Hemisphere upon which it shines, the Air is carried from the Sea to the Land, and so causes a Wind from the Sea: Whereas when the Sun is set, because the Earth preserves its Heat much longer than the Waters, which lose theirs in a very little while (according to that Law, *The less solid Bodies are, the less while do they preserve their Motion*) therefore more Vapours must then arise out of the Land than out of the Water, and consequently, they will carry the Air along with them from the Sea, and so cause a Wind *from* the Land.

CHAP. XII.

Of MISTS and CLOUDS.

1. How Mists and Clouds are formed.

SO long as the Vapours and the Exhalations which accompany them are in so great Motion as to produce Winds, and to hinder their Particles from uniting together, it is impossible that they should so much darken the Air as to be perceiv'd, because the Action of the Light which passes through it, is not at all interrupted, nor any ways reflected; but when these same Vapours [1] come to lose the Agitation they were in by Degrees, and to stop in any particular Place in a large Quantity, and the Particles of them to unite together; they must then necessarily hinder the Action of the Rays of Light from passing on beyond them, because there being a great Number of Drops of Water one above another, their several Superficies will reflect them all: And thus the Air becomes dark, and a *Mist* or a *Cloud* begins to appear in the Place where

1. *To lose the Agitation they were in*, &c.) For the Causes of Clouds and Rain. See *the Notes on Chap.* 12. *Part* I. *Art.* 41.

where this Collection of Particles of Water is, and of such a Bigness as the Space which it possesses.

2. That Mists and Clouds are sometimes composed of Drops of Water and sometimes of Pieces of Ice.

2. If the Particles of Water which stop in this manner and are suspended in the Air, retain so much Motion as to slip by each other, they must compose a great Number of very small imperceptible Drops of Water: But if their Motion be entirely ceased, it is evident, that because they stop by each other without any order, they must compose a very thin and very light Body; which not being liquid, ought rather to be called [1] Ice, or very fine Snow, than Water.

3. How Clouds are supported in the Air.

3. But whether a *Mist* or a *Cloud* be made up of imperceptible Drops of Water or Ice, it is certain that neither the one nor the other can fall to the Ground but very slowly; because these Drops of Water or Parcels of Ice have a very large Superficies compared with the Quantity of Matter they contain, and consequently have but little Weight to overcome the Resistance which the Air they meet with makes before it divides it self. To which we may add, that the Vapours which rise out of the Earth, and ascend to a great Height, not only hinder the Matter of which Mists are composed from falling; but may make it ascend still higher, so that *that* which was a Mist, may in a short Time become a Cloud.

4. Of the different Sorts of Clouds which may be formed.

4. It is to be observed also, that if the Particles of Water which ascend in the manner now mentioned, in order to form Clouds, do not go very far before they lose all their Motion; then they do not give the Exhalations, which arise along with them, time to separate themselves; in this Case therefore they must necessarily be blended together: But if the Vapours have Force enough to raise themselves to a sufficient Height, and meet with no Obstacle to hinder them from continuing on in their Course for some Time; then, because they can easily move themselves and fly off, they will get uppermost; so that there will be two Clouds as it were, the highest of which is made up of Particles of Water or Ice, and the lower one of Exhalations only: And if after this, there arises other Vapours and other Exhalations, which ascend in the same manner, they will form a great many different Beds or Banks of Clouds composed of Vapours and Exhalations by Turns.

 CHAP.

1. *Ice or very fine Snow,* &c.) Concerning *Parhelions* and Circles which they call *Halo's*, formed in such Clouds as these by Refraction; See *Hugenius*'s Posthumous Works.

CHAP. XIII.

Of Rain, Drizzle, Dew, and Evening Damps.

1. That Clouds are the Matter of which Rain consists.

AS two contrary Winds may cause a Mist or a Cloud to be formed, by bringing together a great Quantity of Vapours into one Place; so it may happen, that a very strong Wind blowing upon a Mist or Cloud, may carry off its Parts one after another, and make it take the Form of Vapours again, and so in Time all the Clouds may be dissipated: However this is not the usual Way in which they are dissipated: the common Method is, that the Cloud dissolves, and falls all down in *Rain*: The only Difficulty in this Matter is, what should cause the Parts of a Body which is so thin as a Cloud is, to thicken and become so dense as to acquire a Force sufficient to overcome the Resistance of the Air which opposes its Fall.

2. The common Opinion of the falling of Rain.

2. If we believe the common Philosophers or rather the common People, we must say, that this Force is owing to *the Coldness of the Place* where the Clouds are, because it is generally thought that Cold only has the Power of condensing any thing.

3. How Cold may be the Cause of the falling of Rain.

3. I do not say but that Cold may sometimes contribute to this, by making the small insensible Drops of Water which were dispersed about in the Air, meet together and be converted into Rain, which perhaps would otherwise never have met. For, I readily own, that the grosser Parts of the thickening Air, may by approaching each other unite the insensible Drops of Water, which otherwise might never have united together, and consequently make them capable of descending: I also acknowledge, that when the Vapours are just ready to be converted into insensible Drops of Water, the Cold which comes upon them, and which condenses the Air, may assemble a very large Quantity of them together, so that they may be heavy enough to fall down; And this very well explains how it may sometimes rain when it is very clear and before there is any Cloud formed: But I think also that there are other Causes which are more common, by which the Clouds are condensed, and which cause them to be converted into Rain.

4. For

4. That Wind may be the Cause of Rain.

4. For first, it is evident, that when the *Wind* blows against a Cloud and does not carry it entirely along with it; it must make the Parts of the Cloud approach nearer each other, and cause a great many Drops of Water, which were insensible while at some Distance from one another, to join together, and thereby compose very large Drops, whose Weight makes them to descend.

5. That new Vapours added to a Cloud may make it fall down in Rain.

5. It is also evident, that after any Cloud is formed, there may still rise *other Parts of Water in the Form of Vapours*, which may continue to be little agitated after they meet with those which were stopped before, so that by joining with them, they may become heavier and acquire a sufficient Force to overcome the Resistance of the Air which can no longer hinder them from falling.

6. That Heat does the most effectually condense the Clouds into Rain.

6. But that which is the most common and [1] the most effectual Cause of the Clouds being converted into Rain, is the *Heat* of the Air which is near the Surface of the Earth and which is carried up to a considerable Height by some Wind: For this hot Air, arriving at the Clouds, disposes that very fine Snow, of which they are composed, to melt and to condense into a great many small Flakes, which overcome the Resistance of the Air and fall down, and at last being entirely dissolved by the Heat which they meet with in those Places through which they fall, they are converted into Drops of Rain.

7. How the Drops of Rain may be very large.

7. And these Drops will be very large, if the Cloud be dense, and the hot Air gets to the upper Part of it; for then every thing conspires to make the small Drops of Water or Pieces of Ice to join a great many of them together, and to compose very sensible Drops at first, which descend by their own Weight; but which afterwards increase very much by joining themselves with those that they meet with, as they fall through the whole Thickness of the Cloud.

8. How drizzling Rain is made.

8. But if this hot Air reaches to the Bottom only of a very thin Cloud, the Drops must necessarily then be very small; and if besides this the Heat of the Air be very moderate, these Drops will be so very small as not to compose Rain at all but only *Drizzle*.

1. *The most effectual Cause of the Clouds*, &c.) The most effectual Cause of Rain is the weakning of the Elasticity of the Air. See *the Notes on Chap.* 12. *Art.* 41. *of the first Part.*

9. How Dew is made.

9. As to *Dew*, there is no great Difficulty in comprehending how that is formed, if we confider that when it is moft clear and calm, which is the Time when the *Dew* falls, there is always a great Quantity of very fmall Parts of Water, which fly about in the Form of Vapours; thefe gradually lofing the Agitation they were in, gather a great many of them together and fall down in infenfible Drops, which generally ftick to the Leaves of Plants, and then uniting with each other, they are converted into Water, and the *Dew* becomes vifible.

10. Of the Time when the Dew defcends.

10. This generally happens a little before the Sun rifes, becaufe then the Air not having been heated by its Rays for fome Time, is grown colder, and is therefore more fitted to affemble the Vapours which are in it: However, there are Places where the Air grows cool a little after the Sun is fet, and there the Dew muft appear fooner.

11. How Evening Damps are caufed.

11. If the Heat of the Air has been very great all Day, it may happen, in fome Countries, that the Superficies of the Earth may be put into fuch a Motion, as to fend forth Exhalations which rife up into the Air along with the Vapours: And becaufe thefe Exhalations lofe the Agitation they are in, a great deal eafier than the Vapours do; therefore they muft fall down fooner. Now herein confifts *Evening-Damps*; which according as the Places or the Bodies exhaled are, may be very noxious. For it is very probable, that what is exhaled out of any infectious Places or poifonous Herbs may caufe a great deal more Mifchief, than fimple Vapours raifed out of the Bofom of the Earth.

12. A vulgar Miftake concerning thefe Damps.

12. And it is a very great Miftake to think that Perfons may entirely guard againft the Mifchief fuch Damps are capable of doing, by covering up their Heads clofe. For as they are drawn in along with the Air in Refpiration; it is certain that by entering into the Lungs, they will do much more Hurt, and more eafily corrupt the Blood, than they can do by applying themfelves to any external Part of the Body, which is not fo tender.



CHAP.

CHAP. XIV.

Of Snow, Hail, and Hoar-Frost.

IT was observed before, that the Parts of a Cloud may begin to descend though they be not entirely dissolved; and that for the most Part they are not quite melted and turned into Drops of Rain, till they come near the Earth, where the Heat is generally greater than it is higher up in the Air: But if the Particles of a Cloud, which is only condensed and no way melted, fall through nothing but cold Air, then they may reach to the Earth without being dissolved; in this Case, instead of a great many Drops of Rain, we shall have a great many Flakes of *Snow*; which cannot but be white, because the watry Matter of which it is composed is very much interrupted by a large Quantity of Air, whose Pores agree so ill with those of the Ice, that the Light which endeavours to pass through, is more easily reflected back.

1. How Snow is made.

2. If some Part of the falling Cloud be melted, and it afterwards meets with [1] cold Air which freezes it again, it is evident that *that* which then falls down must be *Hail*, and the Figure of the Hail-stones will be so much the nearer to round, the more they were dissolved before; and they will be exactly round, if the Cold by which they are frozen again, comes upon them when they are entirely melted.

2. Of Hail, and the Figure of it.

3. Thus there must be very different Sorts of Hail produced, according to the different Degrees of Heat which is in the Place where the Cloud is dissolved: And if the Heat be but moderate, it may so act upon the extreme Parts of every little Piece of the Cloud, out of which a Hail-stone is formed, as to melt them and reduce them to Water, before it can get to dissolve the internal Parts; and by that time these are dissolved, the external ones may

3. Of Hail-stones in the shape of Pyramids.

1. *Cold Air which freezes it again*, &c.) It is more likely, that as Water in a Vessel in the Summer-time is immediately turned into Ice, by externally applying Salt and Snow; so likewise a Drop, as it falls, may be turned into Ice or a Hail-stone in a Moment, by some particular Vapours mixed together in the Air. See *the Philosophical Transactions, Num.* 231.

may be frozen again by the cold Air through which they pass: So that the internal Parts which are nearest the Center, melting, and by that means growing more dense, join themselves to the external Ones, and so form a Sort of solid Crust; in the same manner as we see the Parts of a dry Tree recede from the Pith towards the Bark, where the Parts are so close and compact like an Arch, that the internal Parts which are condensed afterwards, are forced to retire towards them. And as, in this Instance, the Fibres of the Wood which surround the Pith at a certain Distance, when they come near the Bark and take up a larger Circuit, split in several Places, and make Chinks like Stars, which are more particularly to be seen in the Part where the Wood is cut; so in like manner, the Parts of Water in retiring from the Center towards the Superficies, as they freeze by Degrees, divide from each other in several Places. Thus if it happens that there are three Fissures made which intersect each other in the Center of the Hail-stone, then it will be split and divided into eight Parts, each of which will be in the Shape of a Pyramid, the Base whereof is the eighth Part of the Superficies of the Hail-stone, and the Top of it, the Piece of Ice which before was nearest to the Center.

4. Of another Sort of Hail-stones which are sharper.

4. Sometimes there falls such Sort of Hail-stones as these, and sometimes such whose Pyramids are sharper, so that their Bases don't seeem to be above the two and thirtieth Part of the Superficies of a Sphere; which makes me think, that, in this Case, every eighth Part of the Superficies of the Hail-stone is again subdivided into four equal Parts by three new Clefts. And if their Points and Corners do appear generally a little blunt, so as to be like Sugar-Loaves, it is owing to this; that in these Places the Heat affected them more, and dissolved the Particles of Ice which were there.

5. Of a more surprising Sort of Hail.

5. The Figure of these Sort of Hail-stones is not at all wonderful or surprizing compared with another Sort which are quite flat and very thin, and which are sometimes cut into the Shape of Stars with six Points exactly equal, or into that of Roses with six Leaves, or sometimes into that of six *Flower-de-luces* connected together by the Points; such as are represented in the Figure, only they are much smaller and a great deal more exact.

Tab. XV. Fig. 7.

6. How some Flakes of Snow are formed.

6. Since we never see any such Hail-stones as these but after a very great Wind, there is Reason to think that they are formed pretty nearly in the following manner. First, the Agitation of the Air causes a great many Particles.

ticles of Water, which fly about in the Form of Vapours to meet againſt each other as they freeze, and to compoſe Hail-ſtones ſo very ſmall, that they would not fall down by their own Weight only, if the Wind which blows upwards did not hinder their Deſcent. But the Wind does really blow againſt them, and carries them up ſometimes as far as the lower Superficies of a Cloud, where, by that time they arrive, they are covered over with Vapours which ſtick to them like a very fine Down. And now they may better be called ſmall Flakes of Snow than Hail-ſtones, and are ſomething like to thoſe little Things which come off from ſome ſort of wild Thiſtles, which grow in the Country, towards the End of Summer, and which are ſo very light, that by the leaſt Motion of the Air, they are carried about, ſometimes as far as the Villages, where the Children play with them and call them *Barbes-à Dieu*.

7. How theſe Flakes are diſpoſed on the lower Surface of a Cloud.

7. When this happens, theſe Flakes of Snow range themſelves upon the Superficies of the Cloud which has been made ſmooth by the Wind blowing againſt it; and becauſe they are very nearly equal to one another, their Order is ſuch, that every Flake is ſurrounded by ſix others, except thoſe which are at the Extremities of the Leaf compoſed by them; as any one may eaſily apprehend who has learned but the firſt Elements of Geometry; or as he may ſee with his Eyes, if he places ſeveral leaden Bullets of equal Bigneſs upon a Trencher, or rather ſeveral Counters upon a Table. Theſe latter are beſt for the Purpoſe, becauſe they are flat, as the Flakes of Snow we are ſpeaking of are, the Down on the upper Part of them being rubbed off by their grating againſt the Cloud, and that on the lower Part, by the Wind preſſing upon them as it blows along.

8. That ſeveral Beds or Strata of them may be formed.

8. And there may be ſeveral Beds or ſeveral ſuch Kind of Leaves formed one under another, without their being joined together; for the Wind, which puts them into an undulating Motion, moves thoſe Leaves which are lowermoſt ſomewhat differently from thoſe which are above them. But whether there be only one Leaf, or a great many of them, we may certainly affirm; that every one of theſe ſmall Flakes of Snow, which are round and flat, is the Matter out of which theſe Hail-ſtones in the ſhape of a Star or a Roſe or ſix Flower-de-luces, are immediately formed; for nothing farther is required to compleat ſo ſurprizing an Effect, but only a moderate Heat in the Air.

9. How they are formed into a great many Stars.

9. This warm Air may be driven from ſome Parts near the Earth by the Wind: Which Wind becauſe it can very eaſily blow between two Leaves compoſed of theſe Flakes, where it meets with a direct Paſſage, muſt neceſſarily diſſolve thoſe remaining Particles of Water which ſtick up like Hairs or Down upon the Superficies of every one of the ſmall Flakes. Beſides; this Air, by getting into the ſix triangular Spaces, which muſt neceſſarily be left between the ſimilar Flakes, when they touch one another, muſt alſo diſſolve that very fine Snow which is near the Circumference of them into Water; the Particles of which being put in Agitation by the Heat, join themſelves to thoſe Particles which remain undiſſolved, and as ſoon as they are thus joined, they are immediately frozen again. Thus the Particles of Water which ſtick up like Hairs on the upper and lower Superficies grow flat and are broken, by being melted and frozen again, and every Flake by that Means becomes thinner, and is turned into a ſmall Plate of Ice: And as to thoſe Hairs which melt in the Edges of the triangular Spaces, they grow denſe as they recede towards thoſe which unite every one of the Flakes to the ſix which ſurround it; and thus there are ſix Clefts made in ſix Places of the Circumference where the Heat can moſt eaſily come, which growing narrower as they get nearer the Center; it is evident, that every ſmall Plate of Ice muſt be of the Figure of a Star with ſix Points, ſuch as is here repreſented in A After which the leaſt Shake is capable of diſuniting them and making them fall down to the Earth ſeparately.

Tab. XV. Fig. 7.

10. How Hail-ſtones in the Form of a Roſe, are produced.

10. If the Heat of the Air be a little greater than what was juſt now ſuppoſed, it muſt continue longer in thoſe Places which are moſt expoſed to it, that is, in the ſix Points, and conſequently muſt put them in Motion and make them grow blunt: By this Means, the ſmall Plate of Ice, which before was in the Figure of a Star, will now become like a Roſe, with ſix Leaves, as it is repreſented in B.

11. How Hail-ſtones in the Form of ſix Flower-de luces, are produced.

11. And if the Flakes, of which this Hail is compoſed, were at firſt larger than uſual; it may happen, that, they will not only be divided in ſix Places, in Order to form ſix Points; but that Part out of which one Point is to be formed, may be ſubdivided into three leſſer Points, by two ſmall Fiſſures made on each Side of thoſe Hairs which join to the Hairs of the next Flake; And thus there may be two Points formed on the two Sides, which may bend a little outwards, becauſe the Heat act-

ing

ing with a little more Force there, causes also the Condensation to be something more: Whence it follows, that instead of a single Point of a Star or Leaf of a Rose, there will be formed a *Flower-de-luce*; and instead of an entire Star there will be formed a Hail-stone like that represented in C.

Tab. XV. Fig. 7.

12. If the Heat of the Air act with greater Force still upon these Hail-stones, it will dissolve some of their Parts proportionably more or less; whence it is easy to collect that there may be a thousand different Sorts formed. And if all the Parts of one Leaf be melted, whilst the Parts of the Leaf above and the Leaf below it are approaching towards each other, the Drops of Water that are made by this Dissolution, may serve, like Glue, to join the two Stars together flat-ways, so as to make them but one, with twelve Points in their due Proportion, if they happen right.

12. Of some other Sorts of Hail

13. All these Sorts of Hail-stones are generally very thin and transparent, because the Particles of Ice of which they are composed are very close and compact. But sometimes there fall some that are quite white and larger; the Reason of which is, because they meet with a great many Particles of Water, which fly about in the Air, which stick to them as they fall down to the Earth.

13. Why the Hail-stones are sometimes thicker.

14. As the Vapours lose their Motion when they meet with Hail, so it is easy to apprehend that they may sometimes lose their Motion when they meet with other cold Bodies. And thus it is that *frozen Mists* and *Hoar-Frosts* are formed, which cover the Earth, and stick to the Branches of Trees and to the Hair of Travellers, especially on that Side where the Wind blows.

14. Of frozen Mists and Hoar-frosts.

CHAP. XV.

Of Honey-Dew, extraordinary Rain, and Manna.

HAVING thus treated of *Meteors* which are composed of nothing else but Water; we must not forget to say something of such as may be made up of some fat Matter which is found in the Earth, and which ascends

1. How Honey Dew is formed.

cends in the Form of Exhalations. Here it is to be obſerved, that if, when the Weather is warm and no Wind ſtirring, a conſiderable Quantity of Vapours and Exhalations ſhould riſe up together, and be in ſo great Agitation as to aſcend to ſome Height; then the Vapours, which can eaſily diſengage themſelves, would ſeparate from the Exhalations, and get above them; and the Exhalations whoſe Parts are more entangled, and which cannot aſcend ſo high, would fly about by themſelves in the Air nearer to the Earth. And if it happens that this Air be moderately cool in the Night, the Vapours may continue to be in ſo much Motion as to keep the Form they were in; but the Exhalations, conſiſting of Parts whoſe Figure makes them more diſpoſed to be at reſt, will condenſe themſelves, and gather into a Miſt, which will extend it ſelf over any Country in Proportion to the Quantity of Exhalations. This being ſo, if, when they meet with any dry Bodies, they thicken into a Kind of oily Liquor, in the ſame Manner as we before ſaid, Vapours thickned into Dew; they will then make that *Honey-dew* which is ſometimes ſo troubleſome to the Country-men.

2. Why Honey-dew falls generally upon the Corn, and how it is injurious to it.

2. The Exhalations which compoſe *Honey-dew*, being of an oily Nature, it is evident, that they will ſtick to the dryeſt Bodies ſooner than to any other; and becauſe Corn and ſuch like Plants, are generally very dry, at that Seaſon in which the *Honey-dew* falls, it muſt be upon theſe Sorts of Bodies that it is found in any large Quantity: And it cannot but be very injurious, if the Weather be very clear afterwards, and the Sun ſhoots his Rays upon theſe Plants; for the oily Liquor which they are daubed over with, being capable of great Heat, [1] burns them up and quite corrupts them.

3. Of Showers of Blood.

3. If the Exhalations be condenſed at ſome Diſtance from the Earth, they will form a Cloud and not a Miſt, and by growing ſtill denſer, from ſome of the Cauſes by which Vapours are uſually converted into Water, they will compoſe a kind of oily Drops, which being alſo of a reddiſh Colour, gives Occaſion for them to be taken for a *Shower of Blood*, ſuch [2] as is related in Hiſtory to have fallen ſometimes.

4. The

1. *Burns them up and quite corrupts them.*) *Pliny* teſtifies, *Book* 18. *chap.* 28, that a great many of the Ancients affirmed, *that Dew burnt up by the ſcorching Sun, is the cauſe of the Honey-dew on Corn*, though he himſelf thinks otherwiſe.

2. *As is related in Hiſtory*, &c.) Tit. Liv. Book 42. Sect. 20. *There was a Report of its having rained Blood for three Days at a Town in* Italy; and in ſeveral other Places of the ſame Author. So likewiſe *Pliny*, *Book* II. *Chap* 56. *It rained Blood when* M. Acilius *and* C Porcius *were Conſuls.*

4. The Exhalations being very different in different Countries, according to the particular Nature of the Places, they must produce very different Effects. Out of these, *Manna*, for Instance is formed, which is of such frequent Use in Physick; and which is gathered in the Morning from certain Trees to which it sticks. Of this there can be no Doubt, because it always sticks on that Side where the Wind blows. As to any Thing further; as, that *Manna* is not found upon all Plants, the Reason is, because the Exhalations don't every where find Superficies proper for them to stick to.

4. Of Manna.

CHAP. XVI.

Of Thunder, Lightning, and Thunderbolts.

THUNDER, *Lightning*, and *Thunder-bolts*, are the most surprising of all Meteors; and because they are very often accompanied with Rain and Hail, the Order of Things requires, that after having treated concerning these, we should endeavour also to explain how the other are produced. Let us imagine then, that sometimes a great many Clouds are formed one above another, which are composed alternately of Vapours and Exhalations, raised by the Heat, at different Times, out of the Bowels of the Earth. Let us consider further, that the Season most proper for this Purpose being the Summer, during which, the Air near the Earth has Time to grow hot, especially if it be calm; it may happen, that some Parts of this Air, may be carried up, by some Wind that rises afterwards, to one of the highest Clouds, and blow against the upper Part of it; so that it will condense, almost in a Moment, that very fine Snow of which the Cloud is composed, by making those Parts which are uppermost approach nearer to those which are under them: By this Means this Cloud will descend whole upon the next Cloud under it, and that with a considerable Swiftness, without this latter being able to descend at all; because it is hindred, by the usual Causes which support the Clouds at a certain Distance from the Earth, and by the Wind which we just now supposed to be arisen. This being so; the

1. How Thunder is produced.

Air

Air which is between the upper and lower Cloud, is forced out of its Place in ſuch a manner, that *that* which is near the extreme Parts of the two Clouds gets out firſt, and ſo gives an Opportunity for the extream Parts of the upper Cloud to ſink down a little lower than the Middle of it does; and ſo to comprehend a great Quantity of Air in it, which ſtriving to get out by that 1 very ſtraight and irregular Paſſage which remains, it is very eaſy to imagine that the Manner in which it gets out muſt cauſe it to make a great Noiſe, for the ſame Reaſon that the Air which comes out of an Organ through the Pipes makes a great Noiſe. Thus we may hear the Noiſe of *Thunder* without ſeeing any Lightning.

2. How Thunder may make a prodigious Crack.

2. I confeſs indeed that this Sort of Thunder cannot make any very great Noiſe; But becauſe the Exhalations which are ſometimes between the two Clouds, one of which falls with great Force upon the other, are generally ſo compreſſed in ſome Places, that the Parts of the ſecond Element which were mixed with the Matter of the firſt Element, among their little Branches, are driven out thence; it happens by this Means, that the Exhalations which are in theſe Places, ſwimming only in the Matter of the firſt Element, are converted into Fire; which communicating it ſelf in a Moment to every Thing that is combuſtible all round, it dilates the Air prodigiouſly, and proportionably increaſes the Velocity with which it gets out from between the two Clouds: And this cauſes, not a rumbling Thunder, but a terrible Crack.

3. How Lightning is made.

3. Further; as the Flame which proceeds from Exhalations is the pureſt of all, ſo is it very proper to puſh forward the ſmall Globules of the ſecond Element, with which

1. *Very ſtraight and irregular Paſſage*, &c.) ' It is very common with ' us to hold Water between our two ' Hands joined together, and then by ' compreſſing them, to ſqueeze it out ' like a Syphon. Something like ' this you may ſuppoſe to be done ' there. For the Straitneſs of the ' Clouds when they are compreſſed ' together, forces out the Air which ' is in the Middle ---, and drives it ' on as an Engine does.' *Seneca's* Nat. Quæſt. Book 2. Chap. 16.

But it is far more probable, that Thunder is produced not by the falling of the Clouds, but by the kindling of ſulphureous Exhalations. Thus *Aurum Fulminans* makes a great Noiſe. For *ſome ſulphureous Steams, at all Times when the Earth is dry, aſcending into the Air, ferment there with nitrous Acids, and ſometimes taking Fire, cauſe Lightning and Thunder and fiery Meteors. For the Air abounds with acid Vapours fit to promote Fermentations, as appears by the ruſting of Iron and Copper in it, the kindling of Fire by blowing, and the beating of the Heart by means of Reſpiration.* Newt. Opt. p. 355. See *alſo the Philoſophical Tranſactions*, *Numb.* 123.

which it is ſurrounded, to the Objects which are every where about; and they reflecting it to our Eyes, we muſt neceſſarily have the Sight of thoſe Objects raiſed in us, in the ſame Manner as if the Sun or any Flame ſhone upon them; And in this conſiſts *Lightning*, which, according to what was formerly ſaid concerning Light and Sound, muſt be ſeen before we hear the Thunder, notwithſtanding they are made together, or perhaps the Thunder is a little before the Lightning.

4. Why the ſound of the Thunder laſts longer than the Lightning.

4. Neither ought we to think it ſtrange, that the Thunder continues longer than the Lightning, if we conſider, that the Agitation of the Air, which produces the Sound, may continue on, after all the Exhalations which produce the Lightning are entirely conſumed. But we ſhould add to this, that the Clouds and a great many other Bodies likewiſe which are upon the Earth, cauſe ſeveral Echoes which make that rumbling which we hear after the great Crack of Thunder is over: And this is confirmed from hence, that the ſame Cauſe which produces an Echo with Reſpect to one particular Place, will not always produce one with Reſpect to another Place; and thus likewiſe, the ſame Clap of Thunder is not heard in the ſame Manner in all Places.

5. How it lightens without Thunder.

5. As it may thunder, as was ſaid before, without Lightning, ſo it may happen likewiſe to lighten [1] without Thunder; for the upper Cloud may be ſo ſmall, and may alſo fall ſo ſlowly upon the lower one, that the Air may not acquire a ſufficient Agitation to produce any Noiſe. But notwithſtanding this, the Exhalations may be ſo compreſſed, that all the Parts of them ſwimming only in the Matter of the firſt Element, they may take fire all at once in order to make a Flaſh.

6. That the Rain ought to fall with great Force every time it thunders.

6. Further; As the Heat, which makes a Cloud grow ſo heavy, as to fall very quick upon another Cloud, muſt alſo be ſufficient to diſſolve ſome Part of the Snow of which the Cloud conſiſts; it follows that at every Clap of Thunder, there muſt fall down a very great Quantity of Rain. And ſo we always ſee there does, if the Thunder be directly over our Heads.

7. That

1. *Without Thunder,*) It very often happens, that the Thunder, being at a very great Diſtance, is not heard. As *Seneca* very well obſerves, ' What ' then, *ſays he*, does it not alſo lighten ' ſometimes in a calm Night, ' When the Stars appear? But you ' are to underſtand, that there are ' Clouds in that Place from whence ' the Lightning comes, though the ' ſwelling of the Earth will not ſuffer ' us to ſee them.' *Nat. Quæſt.* *Book* 2. *Chap.* 26.

7. That the Stories of Thunderbolts are false.

7. That which is commonly called Thunder, if it breaks and tears any Thing to Pieces, is then called a *Thunder-bolt*. And becaufe it is a general Notion amongft the People, that the hardeft Bodies have the moft Power to fpoil other Bodies; therefore they believe, that befides the Light and the Flame which come out with fo much Violence from between the Clouds, there comes out alfo a very hard Body which they call a *Thunder-ftone* ; And if we don't fee one of thefe fall, at every Clap of Thunder, the Reafon is, they fay, becaufe it does not always dart it felf towards the Earth, but gets out at a Part of the Cloud that looks another Way. But if this were fo, it is impoffible but that one of them fhould have been feen to fall at fome Time or other, in fome of the Streets of this * great City, or in fome Court, or on the Roof of fome Houfe; which no Perfon, that I know of, can affirm that they have feen. And it is a very weak Reafon, to fay, that we do not fee them, becaufe they are not darted directly againft the Earth; for if they move flanting or upwards, they muft at laft fall down by their own Weight.

* *Paris.*

8. That this Stone is of no ufe to explain the Effects of Lightning by.

8. But there is no Need of having Recourfe to a hard Body in order to explain the more common Effects of Lightning: For if we confider that Gun-powder which takes Fire in a Cannon, hath nothing of Hardnefs in it, and yet has Force enough to drive out a Bullet with incredible Swiftnefs, and fometimes to fplit or break in Pieces the Cannon it felf ; we fhall be convinced that there is no Need of a *Thunder-ftone* to tear Bodies in Pieces in the Manner we fee them.

9. How it is poffible for a hard Body to be generated in the Air.

9. Not that it is impoffible for a hard Body to be generated in the Air, which may be taken for this imaginary Stone; if there fhould be in the Air any volatile Salts, mixed with fulphureous Exhalations, and any other more terreftrial Exhalations, fuch as thofe which fettle like Mud to the Bottom of Rain-water, which ftands covered for fome Time: For we find by Experience, that Sulphur, Saltpetre, and this Mud dried, if they be mixed together in a due Proportion, will be converted into a very hard Stone by the Fire as it were in a Moment of Time.

10. Why Lightning falls generally upon the higheft Places.

10. Nor is it at all wonderful that Lightning fhould fall upon Bodies which are at the greateft Height from the Ground, fuch as the Tops of Towers, fooner than upon thofe that are lower : For, the Clouds where the Thunder is generated, being very high, and the Opening being generally on the Sides of them; the Exhalation which darts out

out thence, and which moves flaunting, must strike against the Bodies which are very high. To which may be added further; that if two Clouds which are joined together at their Extremities, be about to break in the lower Part, it ought generally to be in a Place, directly under which there is some very high Body; because this Body resisting at first the Descent of the Air, makes it divide and separate on each Side, and this causes the Cloud, which has the same Determination, to open exactly in this Place, where consequently the Lightning can the most easily descend.

11. The Cause of several Effects of Lightning.

11. It is also easy to apprehend how Lightning may burn Mens Cloaths and Hair, without doing them any other Mischief; and sometimes, spend its whole Force upon such Things as resist it most; [1] in breaking the Bones, for Instance, without sensibly damaging the Flesh: For, there being very different Sorts of Exhalations, some of them may be like Sulphur, the Flame of which is very light, and will take hold only of Bodies that will easily burn: On the other Hand, some of them may be very subtle and penetrating, much of the same Nature as volatile Salts or *Aqua-Fortis*, which will not meddle with Bodies that are very soft, but exert their whole Force upon hard Bodies, so that they will dissolve Bones or Iron. It is very true, that a Bone may also be broken only by the shaking of the Air, in which that terrible Noise of the Thunder consists, when it is very near us: For if the Sound of a very large *Bell* will sometimes make a Man who is very near it shake so as hardly to be able to stand upon his Legs; the Noise of Thunder may be such as is capable of breaking a Bone; And the Flesh may seem not to be hurt, or at most only bruised; because that is so soft as to yield any way without breaking.

12. That the Sound of Bells may drive Lightning away.

12. *Lastly*, There is some Reason for affirming that the Sound of Bells may cause the Thunder to cease; because the Air which is near the Bell, shakes that which is higher up, and this Air may so shake the lower Cloud as to make it

1. *In breaking the Bones*, &c.) 'Silver is melted without hurting the 'Bag; and a Sword dissolves when 'the Scabbard is whole; and Iron 'melts about the Pikes without inju-'ring the Wood: Wine continues 'stiff when the Hogshead is broken, 'but this Stiffness does not last above 'three Days.' *Seneca's Nat. Quæst. Book* II. *Chap.* 31. 'There is a third 'Sort of Lightning, which they call '*bright Lightning*, of a most surpri-'sing Nature, which empties Hogs-'heads without touching what they 'are covered with, and leaves no 'Marks behind it; Gold and Cop-'per, and Silver, are melted with-'in, when the Bags are not burnt 'at all, nor the Wax-Seal in the least 'disordered, *Pliny, Book* 2. *Chap.* 51.

it fall down in Rain before the upper Cloud gets ſo low: And when this upper Cloud comes afterwards to fall, it can impell the Exhalations in the open Air only, where they have no Opportunity of taking Fire, becauſe they are not compreſſed together. Beſides, when Part only of the lower Cloud is fallen down, the ſhaking, impreſſed upon the Air by the Bell, may diſpoſe the Exhalations which are above the Part which opens, to take their Courſe that Way; ſo that the Matter out of which the Lightning is formed, being wanting in the Place where it ſhould be formed, it is no Wonder that there is not any at all produced.

CHAP. XVII.

Of the RAIN-BOW.

1. What is meant by a Rain-bow.

THE common People are not more aſtoniſhed when they hear the Noiſe of Thunder, than the Philoſophers are ſurpriſed, when they ſee thoſe Colours, in the Shape of a Bow, which appear on a ſudden, in rainy Weather, in that Part of the Air which is oppoſite to the Sun; and which ſometimes diſappear alſo in a Moment. Theſe Colours, are called the *Iris* or *Rain-Bow*; the Cauſe of which has been for a long Time ſearched after, but nothing found out ſo as to ſatisfy any reaſonable Perſon, till this laſt Age. I ſhall give ſuch an Explication of it as I hope can be maintained. But that we may lay aſide all Prejudices, and not engage our ſelves in confuting a great many Opinions which ſome Philoſophers have propoſed upon this Subject; let us imagine ourſelves to be the firſt who have laboured to find out the Cauſe of this Meteor.

2. A general Conjecture about the Rain-bow.

2. The firſt Thing that I obſerve, is, that whenever we ſee any Colours, there muſt always be ſome Light; the Rays of which are either reflected to us by the Superficies of ſome opake Body, or tranſmitted through ſome Sort of tranſparent Body, which at the ſame Time it ſelf is tinctured with ſome Colour; or elſe paſs through a Body entirely tranſparent, but ſo as to be ſome way refracted. And ſince Experience does not teach us any other but theſe,

these three Ways of discerning Colours, it is unreasonable to think that there should be a fourth Way which is not comprehended in any of these. And since it is not at all probable, that there should, in so short a Time, be formed in the Air any very large opake Body, which is able to reflect the Light, in such a manner as it must do, to cause us to see a Rain-bow; or any kind of transparent Body, which is at the same Time tinctured with Colours proper for the like Purpose: And since we are further assured, by Experience, that the Air is full of Drops of Water, which are entirely transparent and of no Colour at all; we may reasonably conjecture, that it is these Drops of Water, by which the Light is refracted in passing through them, that make us perceive the Colours, by transmitting the Rays to our Eyes with Modifications proper and necessary to excite such Sensations.

3. That a great many of the Sun's Rays, which fall upon the Drops of Rain, are sent back to the same Place they came from after two Refractions and one Reflexion. Tab. XVI. Fig. 1.

3. This is indeed a Conjecture only; But in order to see whether it be well or ill founded, let us consider what must become of Rays, which, coming from a lucid Body at a very great Distance such as the Sun is, fall upon a watry Body, of a spherical Figure, as we know every Drop of Water is. Let us then examine the Scheme; in which we suppose ADKN to represent a Drop of Rain, and the Lines EF, BA, ON, and such like, which come all from the same Part, to be Rays coming from the Sun's Center, which we consider as parallel to each other, because of the vast Distance betwixt the Sun and us. This being supposed, since it is evident, that the Ray BA only is perpendicular to the Superficies of the Water, because that is the only one which tends to the Center of the spherical Superficies of the Drop, and that all the other Rays fall obliquely upon the same Superficies; it is easy to see, that all the Rays which enter into the Water, except BA, will be refracted towards the Perpendicular. Thus the Ray EF, and those which accompany it, do not go directly to G, but approaching towards the Perpendicular, go from F to K, where without doubt some of them pass through into the Air, which has Pores there fit to receive them; but as to others, which are not thus disposed to continue on in the same Way, they must necessarily be reflected within the drop of Water, along the Line KN, so that the Angle of *Reflexion* may be equal to the Angle of *Incidence*. After this, the Ray KN, and such like, falling obliquely upon the Superficies of the Air, which surrounds this small Sphere of Water, cannot enter into the Air, without be-

ing refracted and going from the Perpendicular LM: Wherefore instead of going directly to Y, they must go towards P.

4. That there are some other Rays which falling upon the Drops of Water, are sent back to the same Place they came from, after two Refractions and two Reflexions.

4. It is to be observed also, that some of the Rays which come to N, do not go out into the Air, till they are reflected again to Q; where, after being refracted, like the rest, they do not go directly to Z, but turn from the Perpendicular TV towards R. But because we are not considering any of the Rays of Light, but those only which can affect the Eye, when it is placed a little lower than the Drop, as about P; we may affirm that those which are reflected from N to Q are useless, because they do not come to the Eye: But then we are to take Notice, that there are others as 2 3 and the like, which being refracted from 3 to 4, and reflected from 4 to 5, and again reflected from 5 to 6, may at last, by being refracted at 6, come to the Eye at 7, which is beneath the Drop.

5. Useful Observations concerning the Rays of Light which come out of the Drops of Water.

Tab. XVI. Fig. 1.

5. These Things are easily understood in general. But if we would know exactly how much every particular Ray is refracted, we must do it by Calculation: And upon such Calculation it appears, that those Rays which fall upon the fourth Part AD of the Sphere, go on in such Lines as are here represented in the Drop ADKN, which if we examine, we shall make three remarkable Observations. The first is, that the two Refractions which the Rays of Light undergo at their entering in and coming out of the Globe of Water, are made both the same Way, so that the latter does not at all destroy the Effect of the former. The second is, that amongst all the Rays which come out of the Part of the Sphere AN, only NP and some few that are very near it, are powerful enough to raise any considerable Sensation, because only those come sufficiently thick and very nearly parallel, the Rest are very much diverging, and separate further from each other when they come out of the Globe, than they did when they entered in. The third is, that there is a Shadow beneath the Ray NP; for since there is no Ray of Light which comes out of the Part of the Globe N 4, it is the same thing as if this Part were covered with an opake Body: We may also affirm that the Ray NP has a Shadow above it, because the Rays which are there, have no Effect, and therefore are no more to be considered than if they were not there at all.

6. Fur-

6. Further; [1] It appears by Calculation, that the Angle ONP, which the Ray NP makes with the Line ON drawn

6. That we may consider three Sorts of effective Rays.

Tab. XVI. Fig. 1.

1. *It appears by Calculation, &c.)* *Cartes*, in Order to find the Diameter of the Rain-bow, searched out all the Angles which parallel Rays, falling upon a refracting Sphere and coming out after one or two Reflexions made by the Superficies of it, make with the Axis of Vision, taking at Pleasure sometimes one and sometimes another Angle of Incidence. Thus he gained his Purpose by going a great Way about, and in a Method not at all necessary, and which is also very far from geometrical Exactness. What he did thus by repeated Tryals, the famous Dr. *Halley* has done in a plain and direct Method, in his Discourse upon the Rain-bow (*in the Philosophical Transactions Numb.* 267.) which it will not be amiss more fully to explain in this Place. It is to be observed therefore ;

That it is necessary, that of the Rays which fall parallel and contiguous upon a refracting Sphere, those that are affective or proper to produce a Rain-bow, must also come out of the Sphere parallel and contiguous. Otherwise they will not come thick enough to the Spectator's Eye, to exhibit those vivid Colours of the Rain-bow. Whence it follows,

That those effective Rays, which come out after one Reflexion made by the Superficies of the Sphere, have all the same Point of Reflexion: Those which come out after two Reflexions, are parallel while they are reflected, that is, from one Point where they are reflected to another: Those after three Reflexions, have all the same middle Point of Reflexions: Those after four, have their reflected Parts, which join the second and third Points of Reflexions, parallel. And so on in a great many such like Reflexions.

Tab. XIX. Fig. 1.

For let IZE, be a great Circle of a refracting Sphere; Let the parallel and contiguous Rays and which lie in the Plane of it, RI, *ri*, fall upon it; and after they are refracted, let them meet in the same Point of the Circumference Z, and then after they are reflected from thence, let them go out in the Lines EM, *em*. It is manifest from the Nature of the Circle and of Reflexion, that the reflected Rays ZE, *Ze*, are respectively equal to ZI, *Zi*, and therefore have entirely the same Position with them, both with Respect to the Sphere and to each other. Whence it follows, that since the Refractions in E, *e*, and in I, *i*, are equal, and the incident Rays RI, *ri*, parallel; the emergent Rays EM, *em*, will be parallel also. Whence, on the contrary, it is easy to see, that if the Rays are effective, they have one and the same Point of Reflexion.

Tab. XIX. Fig. 2.

For the same Reason it will easily appear, that the effective Rays RI, *ri*, which go out after two Reflexions, have their reflected Parts ZY, *zy*, (which connect the Points of Reflexions Q and Y, *z* and *y*) parallel, and ought to have that Position which was mentioned of the reflected Rays in the several Reflexions. Whence it follows further,

That the effective Rays have their Angle of Incidence so ordered, that if there be but one Reflexion, its nascent Increment or smallest Increase, is double the Increase of the Angle of Refraction made in the same Time. If there be two Reflexions, the first Increment is triple the latter. If there be three, quadruple ; If four, quintuple, and so on.

Tab. XIX. Fig. 1.

For it is manifest, that the very small Arch Ii, is the nascent Increment of the Angle of Incidence: And if the Semidiameters CI, CZ be drawn; since CIZ or CZI is the Angle of Refraction, the Angle *i* ZI will be the Increment of the Angle of Refraction generated in the same Time, and the Arch I *i* double the Angle *i* ZI,

Tab. XIX. Fig. 2.

Here also I*i* is the nascent Increment of the Angle of Incidence; And if the Semidiameters CZ, *Cz* be drawn, since CZY,

drawn from the Sun's Center, is forty one *Degrees*, and thirty Minutes. And since, besides those Ray which we suppose

CZY, Czy are the Angles of Refraction, (because ZY is parallel to zy) the Angle ZCz or the Arch Zz is the Increment of the Angle of Refraction. But $2Zz$ ($=$ Arch ZY $-$ Arch zy $=$ Arch IZ $-$ Arch iz) $= Ii - Zz$. Therefore $Ii = 3\,Zz$.

By much the same Way of arguing it may be proved, that if there be three or more Reflexions, the Ratio of the nascent Increments of the Angle of Incidence and Refraction, is such as we have assigned.

Wherefore, in Order to find out the Angle of Incidence of a Ray which is effective after a given Number of Reflexions; we must find out that Angle, whose nascent or infinitely small Increment, bears the same Proportion to the Increment of the correspondent Angle of Refraction, made at the same Time; as the given Number of Reflections increased by Unity, bears to Unity. And this Angle will be determined by the following *Lemma*.

Lemma.

Tab. XIX. Fig. 3.

Let ABC be an obtuse angled Triangle, from whose Vertex A let the Perpendicular AD be let fall upon the Base BC produced. I say, that the Sides AC, AB remaining the same, the nascent Increment of the external Angle ACD, is to the Increment of the Angle ABC made in the same time, as BD to CD.

Demonst.

Imagine the Side AC to be turned about the Center A; And by this Motion its extreme Point C to carry the Line BCD into the Position Bcd, so that the Angles CAc, CBc, by the nascent Increments of the Angles BAC, ABC: And let cC, cD be joined.

The Angle ACD is equal to CAB and ABC; and the Angle A cd, is equal to cAB, and ABc. Therefore the Excess of Acd above ACD, or the nascent Increment of the Angle ACD is equal to CBc and CAc. Now because the Angle AcC differs but infinitely little from a right Angle, the Circle described on the Diameter AC, will pass through the Points D and c; and therefore the Angles CAc, CDc, insisting on the same Arch of that Circle, are equal. The nascent Increment therefore of the Angle ACD, is equal to CBc and CDc, that is, it is equal to Dcd. But the nascent Angles Dcd, DBc are to each other as their Sines, that is, as BD, the Side of the Triangle BDc to Dc. Now because the Angle CDc is infinitely small, Dc is equal to DC; wherefore the nascent Increment of the Angle ACD, *viz.* Dcd, is to the Increment of the Angle ABC, made in the same time, *viz.* CBc; as BD to CD. Q. E. D.

Coroll.

The nascent Increments therefore of the Angles ACD, ABD, are as the Tangents of those Angles directly; a Line being drawn from the Point B parallel to AC till it meets DA produced, As appears from *Prop.* 4. *Book* VI. *Eucl.*

Problem I.

The Ratio of Refraction being given; to find the Angles of Incidence and Refraction of an effective Ray, after a given Number of Reflexions.

Let any straight Line AC be taken, and let it be so divided in D, that AC may be to AD, as the Ratio of Refraction; and let it be divided again in E, so that AC may be to AE, as the given Number of Reflexions increased by Unity, is to Unity. Having described the Semicircle CBE on the Diameter CE; from the Center A, with the Radius AD, let the Arch DB be described, intersecting the Semicircle in B: Let AB, CB be drawn, then will ABC, or its Complement to two right Angles, be the Angle of Incidence, and ACB the Angle of Refraction required.

Tab. XIX. Fig. 4.

Demonst.

From the Point A, let the Perpendicular AF be let fall upon CB produced, and let BE be drawn; then

ſuppoſe to come from this Center to the Drop of Water, there come others alſo from every Point of the Sun's

then will the Triangles, ACF, ECB be ſimilar. Now the Sine of the Angle ABC, or ABF, is to the Sine of the Angle ACB, as AC to AB or AD, that is, in the given Ratio of Refraction (*by Conſtruct.*) Suppoſing therefore ABF to be the Angle of Incidence, ACB will be the correſponding Angle of Refraction. Further, the naſcent Increment of the Angle ABF, is to the Increment of the Angle ACB, generated in the ſame Time, as CF to BF; (*by the Lemma*) that is, as CA to EA, (*by ſimilar Triangles*) that is, as the given Number of Reflexions increaſed by Unity, is to Unity (*by Conſtr.*) Wherefore, the Ratio of the naſcent Increment or the Angle of Incidence ABF, to the Increment of the Angle of Refraction ACB, is ſuch as is required (*by the Obſervations above*) in the Angles of Incidence and Refraction of an effective Ray after a given Number of Reflections. The Angles ABC or ABF, and ACB therefore are the Angles required. *Q. E. D.*

Coroll. 1.

From the foregoing Conſtruction of this Problem; the Rule of the famous Sir *Iſaac Newton*, for finding the Angle of Incidence, which you may find in his *Opticks*, *pag.* 148, may eaſily be collected. For let I be to R in the Ratio of Refraction; then will $AC = \frac{I}{R} AB$; let n be the Number of Reflexions increaſed by Unity, and it will be $nFB = FC$. And becauſe the Angle at F is a right Angle, therefore $ACq - CFq = ABq - BFq$; that is, $\frac{II}{RR} ABq - nnFBq = ABq - BFq$; and therefore $nnFBq - BFq = \frac{II}{RR} ABq - ABq$; and again $\frac{BF}{AB} = \sqrt{\frac{II - RR}{nnRR = RR}}$. Whence (if inſtead of n be put its Value, which in the firſt Rainbow is 2, in the ſecond, 3, in the third, 4, *&c.*) it will be

In Rainbow the { 1ſt. $\sqrt{3}$ RR : / 2d. $\sqrt{8}$ RR : / 3d. $\sqrt{15}$ RR : / &c. } $\sqrt{II - RR}$ :: AB : FB :: the Radius : the Coſine of Incidence.

Tab. XXVII. Fig. 3.

But the foregoing Rules may be found in a more ſimple and expeditious Way yet; if it be conſidered, that the ſmalleſt Increments of Angles or Arches, are to each other, as the Increments of their Sines generated in the ſame Time, directly, and the Coſines themſelves inverſely. On the Center C, with the Diſtance CA let the Arch of the Circle AD be deſcribed; then will DS be its Sines, and ds the Sine of the Arch which exceeds the Arch AB by Dd the ſmalleſt Difference that can be. Let Dp be drawn perpendicular to ds, and dp will be the Increment of the Sine DS generated in the ſame Time. Let DC be drawn; then (*by the ſimil. Triangles DCS, Ddp*) it will be SC : CD :: pd : Dd. Wherefore $Dd = \frac{CD \times pd}{SC}$ Conſequently (*the Radius CD being every where the ſame*) Dd or the ſmalleſt Angle DCd is as $\frac{pd}{SC}$ Now the Letters n, I and R ſtanding for the ſame Things as before, and putting ξ for the Coſine of the Angle of Incidence of an effective Ray, and ϖ for the Coſine of the Angle of the Refraction of the ſame; Since n is to 1 (*by the Obſervations above*) as the ſmalleſt Increment of its Angle of Incidence, to the Increment of the Angle of Refraction generated in the ſame Time; and the Increments of thoſe Angles are as the

Sun's Superficies; we ought to examine a great many more effective Rays, and particularly that which comes from

Increments of the Sines directly, and as the Cosines themselves inversely; and (*because the Ratio of the Sines of Incidence and Refraction is given*) the Increments of the Sines of Incidence and Refraction, are to each other (*by Conversion*) as the Sines themselves, or as I to R; Therefore n will be to 1 as I to R directly, and as Σ to σ inversely, that is $n : 1 :: \frac{I}{\Sigma} : \frac{R}{\sigma}$. Wherefore $I\sigma = nR\Sigma$. Putting therefore r for the Radius answering to Σ and σ; $\sqrt{r^2 - \Sigma^2}$ will be the Sine of the Angle of Incidence answering to that Radius, and (*the Ratio of Refraction being given*) $\frac{R\sqrt{r^2 - \Sigma^2}}{I}$ will be the Sine of the Angle of Refraction, and therefore $\frac{\sqrt{I^2r^2 - R^2r^2 + R^2\Sigma^2}}{I}$ will be its Cosine or σ. Wherefore in the Equation $I\sigma = nR\Sigma$, if for σ be substituted its Value, it will be $\sqrt{I^2r^2 - R^2r^2 + R^2\Sigma^2} = nR\Sigma$; And (*squaring the Parts and transposing them*) $I^2r^2 - R^2r^2 = n^2R^2\Sigma^2 - R^2\Sigma^2$. And (*resolving the Equation into Proportion, and extracting the Roots of the Terms*) $\sqrt{n^2R^2 - R^2} : \sqrt{I^2 - R^2} :: r : \Sigma$ the same Proportion as before. *Q. E. I.*

The foregoing Rules may easily be reduced to another Form, which perhaps may appear somewhat more convenient still for finding the Angles of Incidence and Refraction, by Calulation. For putting r for the Radius, S for the Sine of the Angle of Incidence, Σ for its Cosine, and s for the Sine of the Angle of Refraction. Since in the first Rainbow. $3R^2 : I^2 - R^2 :: r^2 : \Sigma^2$. It will be $3R^2 : 4R^2 - I^2 :: r^2 : r^2 - \Sigma^2 = S^2$. Wherefore $S = \frac{r}{R}\sqrt{\frac{4R^2 - I^2}{3}}$. And because $S : s :: I : R$: it will be $s = \frac{r}{I}\sqrt{\frac{4R^2 - I^2}{3}}$. So likewise it will be found in the second Rain-bow that $S = \frac{r}{R}\sqrt{\frac{9R^2 - I^2}{8}}$. $s = \frac{r}{I}\sqrt{\frac{9R^2 - I^2}{8}}$. And in the third $S = \frac{r}{R}\sqrt{\frac{16R^2 - I^2}{15}}$. $s = \frac{r}{I}\sqrt{\frac{16R^2 - I^2}{15}}$. And so of the rest.

Corol. 2.

The Tangent of the Angle of Incidence of an effective Ray, is to the Tangent of the Angle of Refraction; as n to 1. It follows from what goes before, and from the Corollary of the Lemma.

Prob. II.

The Ratio of Refraction being given, and any Angle of Incidence whatsoever: To find the Angle, which a Ray of Light, comming out of a refracting Sphere after a given Number of Reflexions, makes with the Axis of Visions or incident Ray; and so to find the Diameter of the Rain-bow.

The Angle of Incidence being given, and the Ratio of Refraction, the Angle of Refraction is given. Let this Angle be multiplied by twice the Number of Reflexions, increased by the Number two, and from the Product, let twice the Angle of Incidence be taken; the remaining Angle is the Angle sought, *Q. E. I.*

Demonst.

Let CIZE be a great Circle of a Sphere; in the Plane of which let RI be an incident Ray, which after two Refractions in the Points of the Circumference I and E, and one Reflexion between them in Z, comes out in the Line EM. Let EM be produced, till it meets the incident Ray RI, produced also, in

Tab. XIX. Fig. 5.

from the higheſt, and that which comes from the loweſt Part of the Sun. Now the Sun's apparent Semidiameter being

in X; and from the Center C, let the Semidiameters CI, CZ be drawn. Becauſe the Angles CZI, CZE, and alſo the Angles ZIX, ZEX, are equal; CZ produced will paſs through X and biſect the Angle IXE. The Difference of the Angles CZI, ZIX, is alſo equal to IXZ. But CZI or CIZ is the Angle of Refraction, and ZIX is the Difference betwixt that Angle and the Angle of Incidence CIX; Therefore IXZ is the Difference betwixt twice the Angle of Refraction and the Angle of Incidence. Conſequently, the whole Angle IXE, is the Difference betwixt four Times the Angle of Refraction, and twice the Angle of Incidence. *Q. E. D.*

Now let the Ray RI, after two Reflexions in Z and E, come out in the Line *e*R, meeting RI and XE (the firſt being refracted) in R and M. *e*EX, the external Angle of the Triangle *e*EM, is equal to the two Angles, E*e*M, *e*ME; and becauſe the Refractions in *e* and E are equal the Angles E*e*M, ZEX, are equal; therefore the Angles *e*EZ, *e*ME are equal: But it is evident, that the Angle of Reflexion *e*EZ or EM*e*, is double the Angle of Refraction: And it has been demonſtrated, that MXR is the Difference betwixt four Times the Angle of Refraction and twice the Angle of Incidence: Therefore the Sum of the Angles EM*e* or XMR and MXR: that is, the external Angle of the Triangle MXR, is the Difference betwixt ſix times the Angle of Refraction, and twice the Angle of Incidence. *Q. E. D.*

The ſame Method muſt be proceeded in, if there be three or more Reflections. But becauſe ſuch Caſes belong to the third and fourth, *&c.* Rain-bow; which are hardly ever ſeen in the Heavens, becauſe the Rays of the Sun become ſo much thinner by every Reflexion; and becauſe they are very eaſy; I ſhall not ſtay to demonſtrate them.

Suppoſing therefore, that the Ratio of Refraction out of Air into Water, is what the famous Sir *Iſaac Newton* obſerved; (*See his Opticks, p.* 111,) *viz.* as 108 to 81, in the red Rays; and 109 to 81, in the blue; then by Calculation according to the foregoing Rules, the Diſtances of the Colours from the Axis of Viſion (which is confirmed by Obſervation) will be found to be in Rain-bow

Bow	Colour	Degrees	Minutes	
Iſt.	Red	42.	1′.	If the Spectator be turned from the Sun.
	Blue	40.	16′.	
IId.	Red	50.	58′.	
	Blue	54.	9′.	
IIId.	Red	41.	37′.	If the Spectator be turned towards the Sun.
	Blue	37.	9′.	
IVth.	Red	43.	52′.	
	Blue	49.	34′.	

Hence the Breadths of the Rainbows, and their Diſtances from each other, may eaſily be collected; ſuppoſing the Sun to be only a Point. But becauſe the Diameter is about 30′, ſo much muſt be added to the Breadth of every one of the Rainbows; and ſo much muſt be taken from their Diſtances from each other, that their true Breadths and Diſtances from each other may be had. 15′. muſt alſo be added to the Diſtance of the outer-moſt Circle of Colours, from the Axis of Viſion, which paſſes thro' the Sun's Center; and as much muſt be taken from the Diſtance of the inner-

being about fixteen Minutes, it follows that the effective Ray which comes from the higheft Part of the Sun, will fall

innermoft Circle, in Order to have the true Diftances of thofe Circles from the Axis of Vifion.

Prob. III.

In the firft Rain-bow; the Angle, which an effective Ray of any Kind, makes with the Axis of Vifion, being given; to find the Ratio of its Refraction.

Tab. XIX. Fig. 6. Let the Angle of Incidence be got: For that being found, the Angle of Refraction, and confequently, the Ratio of Refraction, will be given, by (*Prob. II.* or *Corol.* 2. *Prob. I.*) Let ABC, be the Angle of Incidence, and, any given Line CA being taken for Radius, let AB be the Tangent of that Angle; which being bifected in D, and CD being drawn, ACD will be the Angle of Refraction, (*by Cor.* 2. *Prob. I.*) Let AE be the Tangent of double this Angle; and having drawn CE, the Angle BCE (*by Prob. II.*) will be half a given Angle, and confequently will it felf be given, Suppofe then AE $=$ S; BA $=$ T; and therefore AD $= \frac{1}{2}$T; AC $= r$; the Tangent of the given Angle BCE $= t$; And becaufe the Line CD bifects the Angle ACE (*by Conftruction*) it will be (*by Prop.* 3. *Book VI, of Eucl.*) AC : CE, $(\sqrt{ACq + AEq})$: : AD : DE. Wherefore DE $= \frac{T\sqrt{SS + rr}}{2r}$. And $\frac{T\sqrt{SS + rr}}{2r} - \frac{1}{2}T = S - T$. And again $T\sqrt{SS + rr} = 2Sr - Tr$. Then (*by fquaring the Parts, and Reduction*) it will be $S = \frac{4Trr}{4rr - TT}$.

Now in order to find out T; let BF be let fall from the Point B perpendicular to CE; Then, it will be, as the Secant of the given Angle BCE, is to the Tangent of the fame, that is, as $\sqrt{rr + tt}$ to t; fo is EB $(\sqrt{TT + rr})$ to BF $= t\sqrt{\frac{TT + rr}{rr + tt}}$. Again, (*becaufe the Triangles* EBF, ECA *are fimilar*) EC, $(\sqrt{SS + rr})$: CA, (r) : : EB, (S $-$ T : BF $= \frac{Sr - Tr}{\sqrt{SS + rr}}$. Wherefore $t\sqrt{\frac{TT + rr}{rr + tt}} = \frac{Sr - Tr}{\sqrt{SS + rr}}$. Then (*by fquaring the Parts*) $\frac{TTtt + rrtt}{rr + tt} = \frac{SSrr - 2STrr + TTrr}{SS + rr}$. And (*by multiplying the Numerators by each other's Denominators, ftriking out the equivalent Terms and by Tranfpofition*) $SSr^4 - 2STr^4 + TTr^4 = SSTTtt + 2STrrtt + r^4tt$. And (*by extracting the Roots*) $Srr - Trr = STt + rrt$. Now the Value of S, before found, being fubftituted in its Room, and the whole divided by $\frac{rr}{4rr - TT}$, the Equation will become $T^3 = 3TTt + 4rrt$, or $T^3 - 3T^2t - 4rrt = 0$. Now by refolving this Equation T will be found, and confequently, the Ratio of Refraction will be found from what goes before. *Q. E. I.*

Now in Order to refolve this Equation, let $V + t$ be put for T, and then it will be changed into this Form $V^3 - 3Vtt - 2t^3 - 4rrt = 0$. Which being reduced by the Rule, which you have briefly demonftrated in *pag.* 272. of the famous Sir *Ifaac Newton's Algebra*; and, fuppofing $r = 1$, and the Secant of the given Angle $\sqrt{rr + tt} = s$, it will at laft come out $V = \sqrt[3]{t^3 + 2t + 2ts} + \sqrt[3]{t^3 + 2t - 2ts}$. Or $V = \sqrt[3]{t^3 + 2t \pm 2ts} + \frac{tt}{\sqrt[3]{t^3 + 2t \pm 2ts}}$. If therefore t be added to this, the Sum will be $=$ T fought. Further, it will eafily appear, that the Sines of the Angles of Incidence and Refraction, are

fall upon the Drop of Water fixteen *Minutes* higher than EF, as you fee (in the fecond Figure relating to the Rain-bow) Tab. XV. Fig. 8.

are $\frac{T}{\sqrt{T^2+1}}$ and $\frac{T}{\sqrt{TT+4}}$, and therefore the Ratio of Refraction is as $\sqrt{T^2+4}$ to $\sqrt{T^2+1}$.

But T may alfo be determined by the following Conftruction. (But it is fuppofed that a ftraight Line of a given Length, may be fo placed between two other ftraight Lines given in Pofition, that when it is produced, it may pafs through a given Point. *See Newt. Algebr. pag.* 279, &c.

Tab. XXVII. Let any ftraight Line be drawn, and in it take CA $= 4t$, and CB $= 3t$, and let BA be bifected in D; having defcribed an Arch of a Circle on the Center C with the Radius CD, let DR $= r$ be infcribed in it; and let AR be joined: Having infcribed the ftreight Line $da =$ DA between DR and AR produced in fuch a Manner as to pafs through the Point C when produced, aC will be $=$ T.

For, let CG be drawn parallel to DR, and meet AR, produced in G; Then (*becaufe the Triangles* GCA, RDA *are fimilar*) as GC is to CA; fo is RD to DA. And again (*becaufe the Triangles* GCa adR *are fimilar*) as GC is to Ca, fo is dR to da or DA. Hence CA is to dR, as Ca to DR. And (*by Compofition*) Ca + CA is to $\left\{\begin{matrix} dR + DR, \\ dD \end{matrix}\right\}$ as CA to dR; but $dR = \frac{4rt.}{T}$

Further CDq − Cdq $=$ dD x dR (*by Prop.* 13. *Book II. of Eucl.*) Whence it follows that $\left\{\begin{matrix} Cd + CD \\ Ca + CA \end{matrix}\right\}$ is to dD, as dR is to Cd − CD. But CA + Ca, is to dD, as CA is to dR. Wherefore as CA is to dR fo is dR to $\left\{\begin{matrix} Cd - CD \\ Ca - CB \end{matrix}\right\}$.

Now if for CA, dR, Ca, CB, be fubftituted their Values; *viz.* $4t$, $\frac{4rt}{T}$, T, $3t$: And the extreme and middle Terms be multiplied by each other, and then reduced; the fame Equation will come out as before, $T^3 - 3T^2t - 4rrt = 0$. If therefore DR be Radius, Ca will be the Tangent of the Angle of Incidence *Q. E. J.*

Coroll.

Hence we have a Method of meafuring the Refractions of Liquors or of any other tranfparent Bodies whatfoever: *viz.* by expofing a Sphere, of any Sort of tranfparent Matter to the Sun, and taking by Obfervation the Angles which the effective Rays of the firft Rain-bow, make with the Axis of Vifion, when they come out of it.

It may be obferved here; that if the Angle, which an effective Ray of a given Kind, in any Rain-bow, makes with the Axis of Vifion, be given; the Ratio of the Refraction of that Ray may be found, pretty much in the fame Manner as before. For, the Conftruction being the fame as then; fuppofe BCA to be the Angle of Incidence of the effective Ray of any Rain-bow propofed; and the Angle ECA, a Multiple of the Angle of Refraction of the fame Ray, according to the Number of Reflexions, increafed by Unity; then will ECB, be half a given Angle, or half its Supplement (*by Prob. II.*). Whence; if CA be called r; AB, T; AE, S; the Tangent of the Angle ECB, t, as before; it is evident, that the fame Equation will always arife $Srr - Trr = STt + rrt$; and that nothing elfe remains, but as in the foregoing Problem, to find the Value of S, and to put it in its Room, in that Equation. Take an Example hereof in the fecond Rain-bow. Suppofe BA to be to DA; as the Number of Reflexions increafed by Unity, is to Unity; then DCA will always be the Angle of Refraction (*by Cor.* 2. *Prob. I.*) and in the fame Rain-bow DA $= \frac{1}{3}$ T, and the Angle ECD double the Angle DCA. In DA produced, let Ad be taken equal to AD. Then will DCd $=$ DCE; And then (*by Prop.* 3. and 22. *Book VI. of Euclid*) $EC^2 : Cd^2 (= CDq) :: ED^2 : Dd^2 (= 4DAq)$ Tab. XIX. Fig. 6.

Tab. XV. Fig. 8.

Rain-bow) the Ray GH does, which being equally refracted as the Ray EF, is turned to I, and from thence to

4DAq.) Whence, ECq — CDq : EDq — 4DAq : : CDq : 4DAq. Alſo, ECq = EDq + DCq + 2 DE x DA; And CDq = CAq + ADq; Which being ſubſtituted for ECq, CDq; it will be, EDq + 2ED x DA ($= \frac{\text{ED x 2DA x ED:}}{}$) $\frac{\text{ED}q - 4\text{DA}q}{}$ (= ED + 2DA x ED — 2DA) : : ED : ED — 2DA : : CAq + ADq : 4ADq. And therefore ED : 2DA : : CAq + ADq : CAq — 3ADq, or ED : DA : : 2CAq + 2ADq : CAq — 3ADq; And *laſtly*, ED + DA (= EA) : DA : : 3CAq — ADq : CAq — 3ADq. Whence it is evident that EA = $\frac{3\text{CA}q \times \text{DA} - \text{DA}^c}{\text{CA}q - 3\text{AD}q}$. Now let S, r, and $\frac{1}{3}$ T, be put for EA, CA and DA reſpectively, and it will be S = $\frac{r^2\text{T} - \frac{1}{27}\text{T}^3}{r^2 - \frac{1}{3}\text{T}^2}$; and putting this Value of S for S in the Equation Srr — Trr — STt — rrt = 0, it will become $\text{T}^4 + \frac{8\,rr}{t}\text{T}^3 - 18\,rr\text{T}^2 - 27r^4 = 0$. Or (putting J for $\frac{rr}{t}$, that is, the Tangent of the Complement of the Angle ECB) $\text{T}^4 + 8\text{J}\text{T}^3 - 18rr\text{T}^2 - 27r^4 = 0$.

Tab. XXVII. Fig. 2.

The Problem being thus reſolved, it may be conſtructed in the following Manner by Means of any Parabola. Let MAC be a Parabola, its Vertex C, the Axis CDFK, the Parameter of the Axis RC; and taking a third Part of this for the Radius of a Circle, let J be the Tangent of the Complement of the given Angle ECB. Let AD = 2J be an Ordinate to the Axis, and let DF be taken equal to $\frac{1}{2}$ C; FK = 2CF, and from the Point K let KH be erected perpendicular to the Axis, and meet the ſtraight Line drawn through A and F, in H. Then having deſcribed a Circle on the Center H with a Radius equal to $\sqrt{\text{HA}q + \frac{1}{3}\text{CR}q}$; and having let fall from the Point M, where it meets with the Parabola the Line MQ, perpendicular to AQ, drawn from the Point A parallel to the Axis; Then MQ will be the Tangent of the Angle ſought to the Radius equal to $\frac{1}{3}$ CR.

For let HK meet the ſtraight Line AQ in I, and the ſtraight Line ML, parallel to the Axis in L; let MQ meet the Axis in P alſo. Now ſince (*by Conſtruction*) $\frac{1}{3}$ CRq = HMq — HAq; and HMq = $\left.\begin{matrix}\text{ML}q\\ \text{PK}q\end{matrix}\right\}$ + LHq; and PKq (= $\overline{\text{DK} \backsim \text{DP}}^2$) = DK$q$ — 2DK x DP + DPq; and LHq (= $\overline{\left.\begin{matrix}\text{LI}\\ \text{MQ}\end{matrix}\right\} + \text{IH}}\Big|^2$) = MQ$q$ + 2MQ x IH + IHq; and HAq = $\left.\begin{matrix}\text{AI}q\\ \text{DK}q\end{matrix}\right\}$ + IHq. : It will be, $\frac{1}{3}$ CRq = DPq — 2DP x DK + MQq + 2MQ x IH.

Further, (*from the Nature of the Parabola*) as ADq : MPq — ADq (= MQq + 2MQ x $\left.\begin{matrix}\text{PQ}\\ \text{AD}\end{matrix}\right\}$) : : CD ($= \frac{\text{AD}q}{\text{CR}}$) : DP. Whence DP $= \frac{\text{MQ}q + 2\text{MQ} \times \text{AD}}{\text{CR}}$. Alſo DK (= 2CD + $\frac{3}{2}$ CR) = $\frac{2\text{AD}q}{\text{CR}} + \frac{3}{2}$CR; And (*becauſe the Triangles* FDA, AIH *are ſimilar*) IH = $\frac{4\text{AD}^c}{\text{CR}q}$ + 3AD. Let theſe Values be ſubſtituted in the foregoing Equation for DP, DK, IH, and it will produce $\frac{1}{3}\text{CR}q = \frac{\text{MQ}qq + 4\text{AD} \times \text{MQ}^c}{\text{CR}q}$ — 2MQq. Or MQqq + 4AD x MQ^c — 2CRq x MQq — $\frac{1}{3}$ CRqq = 0. And *laſtly*, putting MQ = T, AD = 2J, CR = 3r: It will be $\text{T}^4 + 8\text{J}\text{T}^3 - 18r^2\,\text{T}^2 - 27r^4 = 0$. Whence it is evident that MQ is the Tangent of the Angle ſought to the Radius $\frac{1}{3}$ CR.

If

to L, in order to go at laſt to M, where it undergoes an equal Refraction with the Ray NP, and makes with the Line ON, the Angle ONM which contains forty one *Degrees*, and fourteen *Minutes*. So likewiſe, the effective Ray QR, which comes from the lower Part of the Sun, falls upon the Point R, which is ſixteen Minutes lower than the Point F of the Ray EF, whence it is refracted to S, and from thence reflected to T, where going out into the Air, it comes at laſt to the Place V, ſo that the Line TV makes an Angle of forty one *Degrees* and forty ſix *Minutes* with the Ray OT.

7. Of three other Sorts of effective Rays. Tab. XVI. Fig. 4.

7. In computing the Bendings of ſuch Sort of Rays as 2 3 (in the firſt Figure) which we ſuppoſe to come from the Center of the Sun to the lower Part of the Drop, and after two Refractions and two Reflexions, to tend towards the Eye in ſuch Lines as 6 7; we find that that which we call effective, and is repreſented by the Line

If the Roots of this Equation be deſired in Numbers, let the Numeral Tangent of the Complement of the Angle ECB in the Tables, be ſubſtituted for J, and the numeral Radius in the Tables for *r*; And then a numeral Equation will be given, which may be reſolved by the common Rules.

For Inſtance, the Angle which the blue Rays make with the Axis of Viſion in the ſecond Rain-bow, is 54°. 9′. 26″. Half of this, *viz.* 27°. 4′. 48″ is the Complement of Angle ECB. And the Tangent belonging to it, ($\frac{rr}{t}$ = J). 5112854, ſuppoſing the Radius (*r*) 5. Theſe then being ſubſtituted in the foregoing Equation, for J and *r*; there will ariſe the numeral Equation $T^4 + 4.0902832\,T^3 - 18\,T^2 - 27 = 0$. By reſolving of which, T or the Tangent of the Angle of Incidence, will be found to be 2.9775981; And the third Part of this 0.9925327 is the Tangent of the Angle of Refraction; and the correſpondent Sines of theſe, will give the Ratio of Refraction of the blue Rays; Now theſe Sines are to each other, and conſequently the Ratio of Refraction, as $\sqrt{T^2+9}$ to $\sqrt{T^2+1}$; that is, as 42268 to 31410, or as 109 to 81 very nearly.

The aforeſaid Equation has alſo a negative Root, *viz.* − 6.81622765; from whence it may be gathered, that the Ratio of Refraction is very nearly as 347 to 321. For there are two Caſes of Refraction, in which the effective blue Rays of the ſecond Rainbow, make the ſame Angle (54° 9′ ½) with the Axis of Viſion; or when the Ratio of Refraction is as 109 to 81; as in Rain Water, in which Caſe the Tangent of the Angle of Incidence will be 2.9775981; or as 347 to 321, and then the Tangent of the Angle of Incidence will be 6.8162765. And as to this latter Caſe; if the Exceſs of the Sines of Incidence of different Sorts of Rays, above the common Sine of Refraction, be ſuppoſed to be always in a given Ratio; Since the Ratio of Refraction of the blue Rays, is as 347 to 321, that of the red Rays in the ſame Medium, will be nearly as 346 to 321. Whence it will appear by Calculation according to the foregoing Rules, that in ſuch a Medium, the red Colour will be outermoſt, and make an Angle of about $56\frac{1}{3}$ gr; with the Axis of Viſion, and the blue within, in the ſame order as the Colours of the firſt Rain-bow.

Line 6 7, (in the third Figure) makes with the Line 8 6, which comes from the Center of the Sun, the Angle 8 6 7 of about fifty two *Degrees*. Whence it follows, that the effective Ray which comes from the higheſt Part of the Sun's Body, makes with the ſame Line 8 6 an Angle of ſixteen *Minutes* leſs, and that which comes from the loweſt Part of the Sun's Body, an Angle of ſixteen *Minutes* more. Thus ABCDEF being the Courſe which an effective Ray takes, in coming from the upper Part of the Sun, in order to get to F, where we ſuppoſe the Eye to be placed, the Angle 86F is about fifty one *Degrees*, and forty four *Minutes*. So likewiſe GHIKLM being the Courſe which an effective Ray takes in coming from the lower Part of the Sun, the Angle 86M is very nearly fifty two *Degrees*, and ſixteen *Minutes*.

8. Of the three Principal Colours which we ſee on the Drops of Rain.

8. Becauſe we own that there are a great many other Rays which are effective, beſides that which comes from the Sun's Center; therefore there muſt be ſome Alteration made in what we ſaid above concerning the Shadow: For of the three Rays drawn in the ſecond and third Figures, the two extreme ones only have a Shadow adjoining to them, the middle one has none at all. Whence it is manifeſt, that theſe Rays have all the Conditions proper to raiſe the Senſation of Colours like thoſe ſeen by Means of a Triangular Glaſs *Priſm*, which we explained in the firſt Part of this Treatiſe. [2] And we are ſure in particular, that the Ray TV (in the ſecond Figure) ought to appear red, becauſe it is refracted towards the Side oppoſite to the Shadow; that the Ray LM (in the ſame Figure) ought to appear blue, becauſe the Refraction is made

Tab. XV. Fig. 8.

2. *And we are ſure in particular, &c.*] The Drops of Water are here juſtly compared with the Priſm, and the Account of the Shadow is right. But the natural Cauſe of theſe Colours, which the Author aſſigns, is of no Moment, becauſe it depends upon Principles which are not true. We may rather aſſert, that that large Quantity of thick Light, or that Bundle of Rays collected together in a particular Point of the Drop, may be looked upon as a lucid Body terminated on all Sides by a Shadow. Theſe Rays of Light, ſent to the Eye, are different from one another, and are fitted to excite different Colours; and they are differently refracted as they come out into the Air, though they have all the ſame Incidence when they fall upon the refracting Superficies. Theſe different Rays therefore muſt neceſſarily be ſeparated from each other by Refraction, and the various Sorts of them muſt in great Numbers tend different Ways; and conſequently this lucid Point of the Drop muſt appear edged with Colours, that is, red, green, and blue Colours, muſt ariſe from the *Extremities* of the red, green, and blue Images of the Sun (which are painted upon the Eye by the different Drops one above another) in the ſame manner as we find there does in all Bodies, whether bright or opake, when looked at through a *Priſm*.

made by approaching towards the Shadow; and Laſtly, the Ray NP ought to appear Yellow, becauſe there is no Shadow at all on either Side of it. So likewiſe, it is eaſy to ſee, that for the ſame Reaſon the Ray EF (in the third Figure) ought to appear red, LM blue, and 6 7 yellow; ſo that the uppermoſt Ray in the third Figure, produces the ſame Effect as the lowermoſt Ray in the ſecond Figure: It is alſo very evident, that the Rays of the ſecond Figure ought to produce more vivid Colours than thoſe of the third Figure; becauſe the firſt are weakened only three Times in the Places where they are refracted and reflected; whereas the latter are weakned four Times in the Places where their Reflexions and Refractions are made.

Tab. XVI. Fig. 4.

9. What we have now ſaid is exactly agreeable to Experience. For having filled a Glaſs Globe, of about three Inches Diameter, with Water, and held it in the Sun; when my Eye was in the Place marked V (in the ſecond Figure) I always ſaw a very vivid red Colour which ſeemed to cover all the Part about T; and, the Eye remaining in the ſame Place, if I held the Globe a little lower; or if without altering the Globe, I raiſed my Eye a little higher to the Place marked P, I ſaw the Globe, covered as it were with a vivid Yellow, all about the Point N; and if I held the Globe a little lower ſtill, or raiſed my Eye a little higher, ſo as to be in the Place marked M, I always ſaw the Globe covered with Green or Blue, about the Point L. So likewiſe, if my Eye were placed in F (in the third Figure) I ſaw Red in the Place E; and putting my Eye in the Place marked 7, I ſaw Yellow in that marked *6*; and laſtly placing my Eye in M, I ſaw Blue or Green in L. And which is worth obſerving here, the Colours which I ſaw, by Means of the Rays in the third Figure, were leſs vivid than thoſe made by the Rays in the ſecond Figure; for theſe were ſometimes ſo bright, as quite to dazzle one's Eyes.

9. An experimental Proof of theſe Colours.

Tab. XV. Fig. 8.

Tab. XVI. Fig. 4.

10. Nor is it at all ſtrange, that ſome Philoſophers who could not make this Experiment ſucceed, have doubted of the Truth of it: But I thought of a very eaſy Way of doing it, and that is, to try the Experiment in a Place where ſcarce any other Rays can come but only ſo many as will cover over the whole Globe, and to put a Sheet of white Paper in the Place where the Eye ſhould be to ſee the Colours: For then we ſhall ſee

10. An eaſy Way to make the foregoing Experiment ſucceed.

see Red, Yellow and Blue, at the same Time, painted very distictly upon the Paper.

11. A Proof of the Course of the Rays of Light. Tab. XV. Fig. 8.

11. Further; if we go on still to raise or depress the Eye, so that it be not any where in the Space VPM in the second Figure, or F 7 M in the third Figure, we shall see no Colours at all. And there is no Reason to suspect that the Colours which we saw before, were caused by other Rays than those mentioned; for if, for Example, the Glass Ball be covered almost all over, so that the Rays of Light have no Passage any where but at the Places marked F and N, in the second Figure, we shall still see them; whereas we shall see them no longer if only one of these Places be covered; or if any opake Body be put in the Hole of the Glass Globe where the Water is poured in to fill it, which may intercept either of the Rays FK or KN; though all the rest of the Globe be free and uncovered.

12. Why these three Colours are not so easily seen, if the foregoing Experiment be made with a small Globe.

12. Besides the Difficulty of distinguishing these three Colours, by reason of the very great Vividness of the Rays, there may be another, if we make use of a very small Globe, and especially if it be surrounded with very bright Objects: For these Objects shake so much those Parts of the Eye upon which they describe their Images, by the Impression they make, which extends itself a little all round; that the effective Rays which come from the small Globe, and terminate upon the same Capillaments of the optick Nerve, are not capable of making such an Impression as can be perceived. But this Smallness may be compensated by the Number; and a great many very small Globes, such as Drops of Rain are, side-ways and above and below each other, may make the Space which they possess, seem to be filled with these three Colours; provided the Place in which they are, be such, that the effective Rays belonging to them can come to the Spectator's Eye.

13. What Drops of Rain can appear coloured; and of the Axis of Vision. Tab. XV. Fig. 8. Tab. XVI. Fig. 4.

13. Now in order to find out where this Place is, let us imagine a straight Line coming from the Center of the Sun, and passing through the Eye of the Spectator, whose Back is turned towards the Sun; to be continued on to the Part opposite to the Sun, such as VX in the second Figure and 7 X in the third Figure. This Line is that which some others before us, have called the *Axis of Vision,* which because it comes from a Point so very distant, may be looked upon as parallel to all the Lines which come from the same Point. And because a right Line falling upon two parallel Lines, make the opposite alternate

alternate Angles equal; if we imagine that there goes from the Eye of the Spectator, to the Part oppofite to the Sun, (where we fuppofe it to rain then) an indefinite Number of *vifual Rays*, which make three Sorts of Angles with the Axis of Vifion, *viz.* of forty one *Degrees* and forty fix Minutes; forty one *Degrees* and thirty *Minutes*; and forty one *Degrees* and fourteen *Minutes*; and that thefe Rays meet the Drops of Rain which the Sun fhines upon; we fhall eafily apprehend, that thefe *vifual Rays* make Angles of the fame Bignefs, with Lines drawn from the Center of the Sun to thefe Drops; and confequently that thefe Rays are the fame as the *effective Rays* which caufe the Senfation of Colour: Thus in particular, we are fure, that the *vifual Rays* which make Angles of forty one *Degrees* and forty fix *Minutes* with the *Axis of Vifion*, are the very fame as the *effective Rays* of Light, which caufe the red Colour, as VT in the fecond Figure; those which make Angles of forty one *Degrees* and thirty *Minutes*, are the fame as the *effective Rays* which caufe a Yellow, as PN in the fame Figure; And laftly, thofe which make Angles of forty one *Degrees* and fourteen *Minutes* are the fame as the *Effective Rays* which caufe Blue or Green, as ML. So that all that Part of the Air where thefe Drops are, and where thefe *vifual Rays* terminate, ought to appear tinctured with thefe three Colours.

Tab. XV. Fig. 8.

14. *That the Drops which appear coloured are difpofed in a Circle, and make the principal Rain-bow.*

14. Further; it is evident, that if the Eye be placed in the Vertex of a *Cone*, in order to fee the different Objects which are upon the conick Superficies, without having any Regard to their Diftance; thefe Objects muft feem to be in the Circumference of a Circle. Now the Eye of our Spectator is in the common Vertex of three Cones formed by the *vifual Rays*, which make thofe three Sorts of Angles before-mentioned, with the *Axis of Vifion*: And the Drops of Rain which appeared, are in the Superficies of that Cone, whofe Angle at the Vertex is biggeft, and which is the external one of the three. Thofe which appear yellow, are in the Superficies of that Cone, whofe Angle at the Vertex is a little lefs: And Thofe which appear blue or green, are in the Superficies of the third Cone, which is within the other two: All thefe Drops therefore ought to appear like three Girdles difpofed in a Circle, the one red, the other yellow, and the laft green: And becaufe the *vifual Rays* which come from the Eye of the Spectator, make with the *Axis of Vifion*, Angles a little bigger than forty one *Degrees*, and forty fix *Minutes*;

Minutes; or a little leſs than forty one *Degrees* and fourteen *Minutes*; they make alſo greater or leſs Angles with the Lines drawn from the Center of the Sun to the Drops of Rain at their Interſection; whence it follows, that thoſe *viſual Rays* are the ſame with ſome of thoſe which we before called ineffectual, or incapable of raiſing the Senſation of any Colour. So that theſe three Girdles which are red, yellow and green, being cloſe to each other, and no coloured Objects beſides near them, they muſt form the firſt and principal of the two Rainbows that are often ſeen.

15. Of ſome other Drops which ought to appear coloured.

15. It is to be obſerved; that when I juſt now determined the Drops of Water that ought to appear coloured, I excluded thoſe which meet with the *viſual Rays* which are ſuppoſed to come from the Eye of the Spectator, and to make with the *Axis of Viſion*, Angles bigger than forty one *Degrees* and forty ſix *Minutes*: But I did not mean to exclude thoſe Drops, which other *viſual Rays* meet with, and make Angles conſiderably bigger. For it is certain, that if we ſuppoſe an indefinite Number of theſe Rays to come from the Spectator's Eye, and to make with the *Axis of Viſion* Angles of about fifty one *Degrees* and forty four *Minutes*; and other Angles of about fifty two *Degrees*, and others of about fifty two *Degrees* ſixteen *Minutes*, the Drops which they fall upon ought to appear coloured: And particularly, thoſe of them ought to appear red, which are ſeen by the Rays, which make an Angle of fifty one *Degrees* and forty four *Minutes*; becauſe theſe are the ſame as the effective Rays, which after having been twice reflected and twice refracted, have a Power to excite this Colour, ſuch as the Ray FE, in the third Figure. Thoſe ought to appear yellow, which are ſeen by the *viſual Rays*, which make an Angle of fifty two *Degrees*, becauſe they are the ſame as the effective Rays which produce this Colour, ſuch as 6 7 in the ſame Figure. And laſtly, thoſe Drops ought to appear blue or green, which the Rays fall upon that make an Angle of fifty two *Degrees* ſixteen *Minutes*, becauſe theſe Rays are the ſame as thoſe which cauſe blue or green, ſuch as ML in the ſame Figure.

Tab. XVI. Fig. 4.

16. Of the ſecond Rain-bow, and wherein it differs from the firſt.

16. Further, theſe Drops being diſpoſed in a Circle, round about the *Axis of Viſion*, very near each other, and there being no other coloured Objects near them, it is manifeſt, that they muſt form a ſecond Rain-bow; which from what was before ſaid, muſt have its Colours leſs vivid than the firſt, and alſo be diſpoſed the contrary

Way;

Way; for the Red Colour, which appears under the biggeſt Angle, in the firſt Rain-bow, is outermoſt, and the Blue innermoſt; but in this ſecond Rain-bow; the Red which appears under the leaſt Angle, is innermoſt, and the Blue outermoſt.

17. An Experiment to ſee an artificial Rain-bow.

17. This Explication very well accounts for the Difference and Order of the Colours which appear in the internal and external Rain-bow, and is ſufficient to convince us of the Truth of it. And I cannot poſſibly help being fully aſſured that it is ſo, when I ſee that every Time the Wind blows backwards and forwards, and diſperſes every Way, the Water of a Fountain, while it is playing; or when ever I ſpirt Water out of my Mouth and ſcatter it about in a Place oppoſite to the Sun, where its Rays come, and beyond which there is no bright Objects; there always appear artificial Rain-bows, which do not at all differ from thoſe we call natural ones.

18. A Conjecture of ſome modern Philoſophers, and a Confutation of it.

18. For want of conſidering this Experiment, ſome modern Philoſophers have attempted to explain the Rain-bow, by imagining, that there is formed in the Air, a tranſparent Cloud of a particular Figure, which, when the Rays of the Sun paſs through, refracts them in ſuch a manner, that when they come out of this Cloud, every one of them becomes capable of exciting the Senſation of ſome Colour; and all of them together become capable of forming a conick Superficies, at the Extremity of which there is ſome Cloud, by which the Rays are reflected to our Eye, and ſo cauſe the Appearance of a Rain-bow. For, if, without giving themſelves the trouble to examine a great many Things which neceſſarily follow from this Hypotheſis, and which do not at all agree with Experience, they had but conſider'd, that there is nothing at all like this tranſparent Cloud interpoſing, when, what they call artificial Rain-bows are formed, they would have been convinced that their Conjectures are falſe.

19. That it always rains in the Place where the Rain-bow is ſeen.

19. Thoſe that favour the Explication which we have now condemned, always anſwer here; that Rain-bows have been ſeen, when it has not rained; and therefore they muſt neceſſarily depend upon ſome other Cauſes, at leaſt ſometimes, than thoſe which we have aſſigned. But this Obſervation concludes nothing againſt me; For it does not follow, that becauſe there is no Rain where we are, therefore there is none any where elſe. And what I have ſaid concerning the Nature of the Rain-bow, ſeems to me ſo neceſſary, that I think, I may ſafely venture to

affirm

affirm that it always rains in the Place where the Rain-bow appears.

20. Why the Rain-bow seems always of the same Breadth.

20. It will ſtill farther confirm our Opinion; if we can ſhow that all the Properties, which have ever been obſerved in the Rain-bow, may be deduced from thence: And firſt; in our Hypotheſis, it is very eaſy to give a Reaſon why it is always of a certain Breadth, and never increaſes or diminiſhes; for it is manifeſt, [1] that this Breadth muſt neceſſarily be contained under an Angle of thirty two *Minutes*, which is the Difference of the Angles under which we have ſhown the extream Colours ought to be ſeen.

21. Why the Colours are more diſtinct on the red Side than on the blue.

21. The Rain-bow muſt alſo neceſſarily appear more diſtinct on the Red ſide than on the Blue, where the Colour grows fainter gradually, till it vaniſhes. This you will readily acknowledge, if you look upon the Figures where all the Rays which come out of a Drop are deſcribed, and obſerve; that there come no Rays at all out of that Side which we affirm to exhibit the Red Colour; but that there does come out ſome on that Side, which exhibits the Blue; which, though they are not able to cauſe any vivid Senſation, do yet excite ſome Sort of Senſation. Whence it follows manifeſtly, that becauſe thoſe Drops of Rain which are on that Side of the Rain-bow which appears Red, do not ſend any Rays at all to our Eyes, therefore this Colour muſt ceaſe all at once; Whereas the Drops which are near thoſe that appear Blue, do ſend ſome weak Rays, and therefore we ought to ſee a fainter Colour in the Place where they are; and this is the Reaſon why the Blue fades inſenſibly.

22. That two different Perſons do not ſee the ſame Rain-bow.

22. Again, if we conſider that the Drops which appear coloured, are ſeen under a certain Angle about the *Axis of Viſion*; and that two different Perſons have a different Axis, we ſhall plainly ſee, that every Spectator has a particular Rain-bow of his own; And this is confirmed by Experience; (contrary to the Opinion of thoſe who explain the Rain-bow in the manner which we juſt now confuted) firſt in the Water which is ſcattered about in the Air, by a Fountain or out of one's Mouth, in a Place op-

1. *That this Breadth*, &c.] This is a very great Miſtake. For the outmoſt or firſt Rain-bow, is really above two *Degrees* broad, and the inner one above four *Degrees*; but the Colours in the extreme Parts of the Rain-bows are ſo obſcure, that we cannot ſee them of ſo great a Breadth. *See above, Art. 6.* But it was very eaſy for a Perſon to make this Miſtake, who was ignorant of the different Refractions of the ſeveral Colours.

oppoſite to the Sun: for in both theſe Caſes, every Body ſees the Bow in different Drops, and refers it to different Places. So likewiſe in very great Rains, cauſed by the Diſſolution of the Clouds, if a Rain-bow appears, and we can apply the Horns of it to any thing that is fixed, we ſhall find it change its Place as we move backwards or forwards; And this gave Occaſion to this Saying; *That the Rain-bow follows thoſe that flee from it, and flees from thoſe that follow it.*

23. Why the Rain-bow is Part of a Circle ſo much the leſs as the Sun is higher above the Horizon.

23. The Bigneſs of the Rain-bow is more or leſs, as more or leſs of the conick Superficies is above the Surface of the Earth, at the Time of Obſervation; And this Portion is ſo much the leſs [1] as the Inclination of the *Axis of Viſion* to this Surface, is greater; now this Inclination is ſo much the greater as the Sun is higher; The higher therefore the Sun is, the leſs is the Rain-bow.

24. Why a Rain-bow never appears when the Sun is elevated to a certain Degree above the Horizon.

24. It is evident, that if the Sun be more then forty one *Degrees*, and forty ſix *Minutes* elevated above the Horizon, then the Superficies of the Cone, in which the Rain-bow ought to be ſeen, muſt enter into the Earth at a little Diſtance from the Eye: Whence it follows, becauſe there are no Drops of Rain in the Place where they would appear coloured, and this Place is not viſible, being within the Earth; that therefore there can be no principal Rain-bow ſeen at all.

25. That the Rain-bow ſeen from a Plain, can never appear bigger than a Semicircle.

25. Farther; if the Sun be never ſo low, even in the Horizon, it is impoſſible to ſee any more than a Semicircle of a Rain-bow, if we look upon it from a Plain; becauſe its Center is always in the *Axis of Viſion*; which Axis is then upon the Superficies of the Earth, and not the leaſt elevated above it, unleſs you reckon the Height of the Spectator's Eye, which is very inconſiderable, eſpecially if the Rain, where the Bow is, be at any Diſtance.

26. How a Rain-bow conſiſting of an entire Circle, may poſſibly be ſeen.

26. There is no doubt but if when the Sun is in the Horizon, the Spectator were at a very great Height above it; as, for Example, upon the Top of ſome very high Tower; that then the Height of the *Axis of Viſion*, in which the Center of the Rain-bow is above the *Horizon*, would be conſiderable (compared with the Bigneſs of that Circle, part of which the Rain-bow uſes to be) and ſo more than a Semicircle would be ſeen. And we may ſuppoſe the Tower ſo high, and the Rain ſo near the Spectator's Eye, that he may ſee a Rain-bow conſiſting of an entire Circle.

1. *As the Inclination,* &c.] That is, is more elevated, or nearer to a Perpendicular with the Earth, *a very unuſual Senſe of this Word.*

27. How a Rain-bow may appear inverted.

27. And if at the same Time, some Cloud should hinder the Rays of the Sun from falling upon the upper Part of the Circumference of this Circle; then the lower Part only would be seen, and the Rain-bow would appear inverted. Such perhaps those have been that are mentioned by some Authors as very extraordinary Things.

28. Another Way of seeing a Rain-bow inverted.

28. What I have now said does not hinder but that a Rain-bow may be seen inverted by some other Means; For if, when the Sun is above forty one *Degrees* and forty six *Minutes* high, its Rays should fall upon the Superficies of some large smooth Lake, in the Middle of which we suppose the Spectator's Eye to be; and at the same Time there should fall some Rain in that Part of the Air to which the Rays are reflected, it would be the same Thing as if the Sun shined below the *Horizon*, and the *Axis of Vision* extended it self upwards: From whence it follows, that the conick Superficies which determines the Drops that ought to appear coloured, will be entirely above the Surface of the Earth; but because the whole Clouds possess the upper Part of that Superficies, and the Drops of Rain the lower Part only; it is manifest, that an inverted Rain-bow only can be seen.

29. Why a Rain-bow appears so exactly round.

29. Here we ought to remember, that we are not capable of conceiving distinctly in our Minds, the Images of great Distances, but that all Objects beyond a certain Limit, appear at the same Distance; and this is the Reason why there are an infinite Number of Objects, at unequal Distances from us, which yet we judge to be all equally distant from us; Thus, though the whole Superficies of a great many Clouds together, is very unequal and like Waves; and the different Parts of this Superficies are very unequally distant from the Place where we are; yet we generally imagine it to be one single concave sphærical Superficies, of which our Eye is the Center, and we place in it a great many other Objects which are much below it, as the Tops of Steeples, and the Birds which fly in the Air: Now this Mistake, or rather Defect in our Imagination, makes us think that the Colours in the Rain-bow are placed in the same Superficies, and consequently we judge them to be further off, larger, and more exactly round than they really are.

30. That there is no necessity of its raining in the Place where the Rain-bow appears to be.

30. Hence we see, that though the Drops of Rain are absolutely necessary in order to produce a Rain-bow, yet it may happen, that there may fall none in the Place where we imagine the Rain-bow to be.

31. But

31. But I muſt not forget, upon this Occaſion, to take Notice; that if the Drops of Rain that ought to appear coloured, do not happen to be directly againſt a Cloud, but againſt ſome other Objects which the Spectator's Eye is fixed upon; he will imagine that he ſees a Rain-bow painted upon thoſe Objects: And thus I have ſeen ſome painted upon the Sides of Mountains; and a Friend of mine, being not long ſince upon a very high part of the Alps, and looking down into a Valley over againſt him, where it rained very hard, and the Sun, which was at a great height above the Horizon, and on the oppoſite Side to the Rain, ſhone upon the Drops; ſaw a very vivid Rain-bow, which he believed to be upon the Graſs in a Meadow below the Rain.

31. How a Rain-bow may appear on a Meadow.

32. Nor ought I to paſs over in ſilence a very remarkable Obſervation, which is this; that, whereas we have hitherto conſidered the Drops of Water as falling in the Air, and ſucceeding each other in thoſe Places where they ought to appear coloured; we may alſo conſider them, as fixed in ſome Places, where they may continue very nearly round: Thus, a very ingenious Perſon walking upon a Bank one Morning, ſaw on one Side of him, upon the Graſs, in a large Meadow juſt by, a Rain-bow, which ſeemed to change its Place and to go along with him; which he was the more ſurprized at, becauſe it was very clear and no Cloud to be ſeen any where. But his Surprize ceaſed, when upon examining the Herbs in the Meadow, he found almoſt all the Leaves covered with Drops of Water, like thoſe of Dew, which he imagined were cauſed by a very thick Miſt falling, with which the Air was filled but a little before: For, he not being unacquainted with the foregoing Explication, rightly judged, that it was theſe Drops of Water which were the Occaſion of the Rain-bow being ſeen ſo long as they remained upon the Herbs: And he very well knew, that this Bow ought to appear inverted, as indeed it did; becauſe it was only the lower Part of the conick Superficies which ſurrounds the *Axis of Viſion*, that paſſed through the Drops of Water.

32. Of another extraordinary Rain-bow.

33. Further; That there may remain no Doubt but that the exact Roundneſs commonly obſerved in a Rain-bow, depends, as was before ſaid, upon this; that we imagine its Colours to be painted upon a Superficies, which we believe to be in every Part equally diſtant from us; let us conſider, that if the Rain which cauſes the Rain-bow, falls ſo near to us, that we can perceive the different Di-

33. How a Rain-bow may appear inclined.

ſtances of the Drops and Clouds or any other Objects beyond it, upon which we imagine the Bow to be painted; then the Rain-bow will not appear ſo regular, but we ſhall perceive a great many Sorts of Inequalities. For Example, if the Wind blows it towards us, ſo that the lower Drops are nearer us than the higher ones; then the Horns of the Rain-bow will appear to be not ſo far off as the Arch, and conſequently the Bow will ſeem inclined to the Horizon.

34. How the Horns of a Rain-bow may appear to be at different Diſtances.

34. And if the Rain be terminated on the Side of the Spectator in a Plane ſo inclined to the *Axis of Viſion*, as to make an acute Angle on the Left-Hand, and an obtuſe one on the Right; the conick Superficies, which determines the Drops of Rain that ought to appear coloured, muſt neceſſarily interſect thoſe Drops in ſuch a manner, that thoſe which are on the Left Hand, will be much nearer to the Spectator [1] and to the *Axis of Viſion*, than thoſe on the Right: And becauſe theſe two Sorts of Drops form the two Horns of the Rain-bow, they muſt neceſſarily appear at unequal Diſtances: And becauſe the Center of the Bow, is that Point which is equally diſtant from each Horn, therefore we cannot but imagine it to be out of the *Axis of Viſion*.

35. Of other Irregularities in the Rain-bow.

35. In the ſeveral Sorts of Irregularities hitherto mentioned, the Drops of Rain are ſuppoſed to be always exactly round, as they generally are; but if they be ſuppoſed to be made flat on any Side by the Wind, it is eaſy to imagine that there may be produced other Sorts of Irregularities than any that have been hitherto taken Notice of.

36. How a Rain-bow may ſometimes appear broken.

36. If we add to this; that the Rain-bow muſt appear broken in ſome Places, if it ceaſes to rain there, or if the Rays of the Sun are by any means hindred from going thither; and that on the contrary, ſome of thoſe Breaches which appear in ſuch Places, may be filled up again, when it begins again to rain there, or when the Rays, which were hindred by the Interpoſition of ſome Cloud, get thi-

1. *And to the Axis of Viſion*, &c.) Imagine firſt the Axis of Viſion to be perpendicular to the Plane of the Rain-bow; and ſuppoſe two right angled Triangles, one on the right Hand and the other on the left, the *Perpendicular* to each of which is the *Axis of Viſion*, and the *Baſe* to each, half the Diameter of the Bow. Then let the Plane of the Bow be inclined t the *Axis of Viſion*, as the Author here imagines. This being ſuppoſed; becauſe thoſe Angles of theſe Triangles which are next the Eye, muſt remain always the ſame; (*viz. forty three Degrees* in the ſame inner Bow) therefore, when the Bow is thus inclined, the Baſe of the right Hand Triangle muſt appear much longer, than that of the left Hand Triangle,

thither again ; there will remain no one Circumſtance of this Phænomenon, though never ſo inconſiderable, but a very evident Reaſon may be given for it [1].

37. I ſhall here put an End to this third Part ; tho' I cannot ſay that it is compleat : It takes in ſo many Things, that it is impoſſible for any mortal Man to explain them all : And the greateſt Part of thoſe which remain to be accounted for, depend upon ſo many particular Circumſtances, ſome of which require a great deal of Study and Application, and others cannot be found out but by Chance ; that when I ſhall have put my laſt Hand to this Work, and have explained all thoſe other Things which ſhall hereafter come to my Knowledge ; there will ſtill remain enough to exerciſe thoſe who come after, for many Ages. But though what remains yet to be done, is almoſt infinite, and therefore what I have ſaid bears no Proportion to what may be ſaid hereafter ; yet I think it is ſufficient for me, if the Principles which I have advanced and eſtabliſhed, be ſuch, that without changing them, we may be able ſtill to go on in the Way of diſcovering Truth. Wherefore I ſhall now proceed to ſay ſomething of the *Animal Body*, and try if theſe Principles will not help us to ſome Knowledge of that.

37. That one Time or other, ſomething further may be added to this third Part.

1. Concerning what remains further to compleat this Theory, *viz.* to explain *Parhelia*, and thoſe Circles which they call *Halo's*, See the famous Sir *Iſaac Newton's* Opticks, p. 156 and 290. And *Hugen's* Poſthumous Works.





PART IV.

A

TREATISE

OF

Natural Philosophy.

Of the Animated or Living Body.

CHAP. I.

Of the Things contained in this Fourth Part.

1. *What is here meant by the animated Body.*



HOUGH this Term *Animated Body* be extended as well to *Plants* as *Animals*, yet I ſhall now reſtrain it to the Latter. And becauſe there are an infinite Number of Species of theſe, it is an impoſſible Thing to attempt to treat of every one of them in particular; I ſhall therefore content my ſelf with diſcourſing upon the *humane Body* only

ly, which we are more concerned to underſtand than any other. Though this does not hinder, but that what I ſhall ſay, may be applied to the Bodies of *other Animals*, and may help to explain ſuch Properties as the greateſt Part of *Beaſts* have in common with *Man*.

2. The Knowledge that can be gained upon this Subject, is of two Sorts; ſuch as may be acquired by the Help of our *Senſes*; and ſuch as may be acquired by the Help of our *Reaſon*: And we may affirm, that the *latter* does in ſome Meaſure depend upon the former; for it is certain, that *that* which *falls under the Notice of our Senſes*, is a Sort of Rule or Foundation for our *Judgement* in what *does not fall under the Notice of our Senſes*. Wherefore that I may proceed in a right Method; I ſhall begin with thoſe Parts, which *do fall under the Notice of our Senſes*.

2. Of two Kinds of Knowledge.

3. Theſe Parts are alſo of two Sorts: For ſome of them are *external*, and offer themſelves immediately to our View; others are internal, and cannot be ſeen without ſome foregoing Preparation; ſuch as thoſe which are diſcovered by the Diſſection of a dead Body. There is no need of enumerating the former; for every one knows that there is a *Head*, *Arms and Breaſt*, &c. in a Body. Every one knows alſo, that a humane Body conſiſts of a great many different Parts, ſome of which may be divided into other *like* Parts, or Parts of the *ſame Nature*; theſe Phyſicians call *ſimilar Parts*, ſuch as the *Fleſh*. Others may be divided in *unlike* Parts, or Parts of a *different Nature*; theſe they call *diſſimilar Parts*. Thus the *Hand*, which may be divided into *Fleſh*, *Bones*, *Nerves*, *Tendons*, &c. which are Things of a different Nature, is a *diſſimilar Part*. So likewiſe every one knows, that there are ſome Parts of the Body which we make uſe of as *Inſtruments* to perform certain Actions, which we could not perform without them; as, for Example, we uſe the *Hand* to write with; theſe Parts are called *Organical Parts*. It is evident alſo, that there is no Part ſo inconſiderable, but that its *upper*, *lower*, *middle*, *and ſide* Parts may be aſſigned.

3. Of two Sorts of Parts which fall under the Notice of our Senſes.

4. They who treat too largely and intently upon ſuch Things as theſe, as if they were of great Moment and Concern, do more Miſchief than they were aware of; for they thereby vitiate and corrupt the Judgement of a great many who make a Science of *Words* rather than of *Things*. By this Means they accuſtom themſelves to talk on a great while together without any View, and yet they have ſaid nothing but what all the World knew before,

4. That there are ſome Things which it is improper to ſay much about.

except,

except, perhaps, that they have used a great deal of affected Jargon, which may indeed gain them some Credit amongst ignorant People, but which cannot but render them contemptible to those who have any good Judgement in distinguishing betwixt the *Sound of Words*, and the *Reason of Things*.

5. What Benefit may be expected from this Treatise.

5. Leaving therefore the *external* Parts, I shall treat principally of the *internal* ones. But I would have the Reader take Notice here; that the Description which I shall give of some of them, is not so much to inform those who have never seen them; as to bring them again into the Minds of those who have before observed them in a dead Body, or at least, have considered them in the Bodies of some Animals, whose internal Parts are like those of a Man; for it is very absurd to think that any Discourse, be it ever so particular and clear, can inform so much, as can be discovered almost in a Moment by looking upon the Subject.

6. The Reason why nothing has been said about the Bones.

6. I might indeed have mentioned the Bones amongst the Number of those Parts which ought to be treated of distinctly; for they are hid under the Skin, and cannot be discerned by the Eye: But because I do not undertake to write a compleat Treatise upon this Subject, but only consider it with some particular Views, which will afterwards appear; and because we can know by our Feeling only, how the Bones are made, and where they are placed; after we have once observed them in a Skeleton, where we ought to take Notice in the first Place of their particular Figure, and of the Manner in which they are connected together; therefore I shall forbear speaking of them in this Treatise.

CHAP. II.

A general Description of the larger Parts contained in a humane Body.

1. Of the Brain.

THE Bone of the Head, which is called the *Scull*, is full of a soft white Substance which they call the *Brain*, and which extends it self, as it were in a Channel, all along the *Back-Bone*, which the Physicians call the *Vertebræ* to which the *Ribs* are fixed.

2. The Scull does not touch the Brain immediately, but the Brain is covered with a very ſtrong Membrane which is called the *Dura Mater*, under which there is yet another thinner Membrane which they call the *Pia Mater*.

2. Of the Coverings of the Brain.

3. The Trunk of the Body, or that part which is betwixt the Neck and the upper Parts of the Thighs, contains within its Cavity a great many very different Sorts of Parts. The upper Part of this Cavity, which is called the *upper Belly*, or the *Breaſt*, contains the *Lungs*, which are divided into a great many Lobes, and appear to ſurround a Membrane, called the *Pericardium*, being in the Shape of a Purſe, containing the *Heart*, together with a Liquor in which it ſwims, very much like Urine. The Heart is faſtened to the *Vertebræ* by Ligaments which reach from the Baſe of it thither, in ſuch a manner that the Point of it inclines a little to the left Side.

3. Of the Lungs, the Pericardium and the Heart.

4. Beneath the Lungs and Heart, in the Place where the upper Belly ends, is the *Diaphragm*, which is a very thick Membrane, dividing the upper Belly from the lower one, and is ſo ſituated, that when a Man ſtands upright, it is like a Level, which neither inclines to one Side nor the other.

4. Of the Diaphragm.

5. Below the Diaphragm, on the right Side, is the *Liver*, in the lower Part of which is the *Gall-Bag*; and on the left Side is the *Spleen*.

5. Of the Liver, Gall-bag, and Spleen.

6. However, about twenty Years ago, I ſaw a dead Body, in which theſe Parts had a quite contrary Situation; the Liver was on the left Side, and the Spleen on the right; which is ſo rare a Thing, that it has never been obſerved before.

6. An extraordinary Situation of the Liver and Spleen.

7. Betwixt the Liver and the Spleen is placed the *Ventricle*, which receives all that we eat and drink, carried thither through a Channel, called the *Oeſophagus* or *Throat*, which lies along the Vertebræ.

7. Of the Ventricles.

8. The Ventricle has two Holes in it, one to receive the Victuals in at, and the other to let them go out: And at this Part, which is called the *Pylorus* begins the *Inteſtines* or *Guts*, which after ſeveral Windings and Turnings, end at that lower *Hole*, out of which the groſs Excrements of the Body come.

8. Of the Holes of the Ventricle.

9. Properly ſpeaking there is but one *Inteſtine*; but as a long Street has ſometimes ſeveral Names given to different Parts of it: ſo this long Inteſtine, is in imagination divided into ſeveral Parts, which Phyſicians have given different

9. Of the Inteſtines.

different Names to: The firſt Part which joins immediately to the Ventricle is called the *Duodenum*; the ſecond is called the *Jejunum*; the third, the *Ileon*; the fourth, the *Colon*; and, which might be called the fifth and laſt, the *Rectum*: But betwixt the Ileon and the Colon, is a Gut, the Bottom of which is ſtopped up, like a Street which has no Paſſage through it, and this is called the *Cæcum*; ſo that there are reckoned ſix Inteſtines; The firſt three are called the *ſmall* or *ſlender Guts*, and the three other are much *thicker*.

10. Of the Meſentery.

10. All the Inteſtines look at firſt Sight as if they floated about in the Body, without being faſtened; but by taking hold of them, we find that they are faſtened to a certain Membrane which is called the *Meſentery*, and which is fixed to the Vertebræ.

11. Of the Reins and Bladder.

11. Beſides theſe, the lower Belly contains the two *Reins* or *Kidneys*, which are fixed to the Vertebræ, and the *Bladder* which is the Place that contains the Urine.

12. How the Parts of the Body are firſt to be conſidered.

12. It is proper to conſider all theſe Things thus generally, not only before we come to a particular Examination of them, but before we come to the Conſideration of ſome other Things, which are not ſo eaſily diſcovered; becauſe that by having gained a general Knowledge of the Order and Diſpoſition of all theſe Parts, we may form to our ſelves at firſt a general Idea of the whole Machine of a human Body, which is the Object of our Inquiry. I come now to thoſe Things which require more Application, and a more exact Deſcription.

CHAP. III.

Of the Brain, Nerves, and Muſcles.

1. Of the Brain and the Cavities of it.

THE Brain is divided into two Parts; the *Fore-part* and the *Hinder-part*. The Fore-part which is much larger than the other, retains the Name of *Brain*, and the Hinder-part is called the *Cerebellum*. In the Subſtance of the Fore-part there are two Cavities ſo ſituated, that they have a Communication with a third, which is in the Hinder-part; and above the Channel, by which this Communication is made, there is a ſmall Gland called the *Conarium*;

Conarium; which is faſtened by its Baſe to the Subſtance of the Brain, of which it ſelf a Part, and its Vertex ſeems to be ſuſpended in the Middle of all the Cavities. This ſmall Gland is very remarkable, on the account of its great uſe to many Purpoſes, and particularly for this, that though all other Parts of the Brain are *double*, this alone is *ſingle*.

2. Of the ſeven Pair of Nerves.

2. When in diſſecting a dead Body we endeavour to take the Brain out of the Scull in which it is contained, we find it hindred, firſt, by the *Dura Mater*, which ſticks to the Scull in ſeveral Places; ſecondly, becauſe there goes from the Brain *ſeven Pair of Nerves* to different Parts. The two *Optick Nerves*, which we ſpoke of towards the Concluſion of the firſt Part of this Treatiſe, make what the Phyſicians call, the *firſt Pair*: Thoſe which end at the Muſcles of the Eyes, are the *ſecond Pair*: Three Pair go towards the Tongue, the *third, fourth, and ſeventh*: That which goes to the Ears in the *fifth*; And the *ſixth* is that which deſcends through the Neck, and is ſubdivided into a great many ſmall Nerves, which end at different Places, ſome at the Lungs, others at the Heart, Ventricle, Liver, Spleen, Inteſtines, and other Parts of the upper and lower Belly.

3. Of other Nerves of the Body.

3. We ſee alſo a great many *large Nerves*, which come out of that Part of the Brain, which is contained in the Vertebræ, and extend themſelves to all the Members of the Body.

4. Of the Membranes of the Nerves.

4. All theſe Nerves as well as the foregoing ones, are every one of them wrapped up in two very ſtrong Membranes, which ſeem to me to be only the Dura Mater, and Pia Mater continued.

5. Of the Marrow of the Nerves, and of the Muſcles.

5. The internal Subſtance of the Nerves, which may be called the *Marrow* of them, conſiſts of an infinite Number of very fine Capillaments, which at length ſeparate from each other, and diſperſe themſelves to all Parts of the Body, till they become inviſible, and are entirely out of the reach of our Senſes. But a great many of the Nerves divide and diſperſe themſelves in ſuch a manner, that, after the Capillaments of which they conſiſt, are as it were, mixed and blended, with ſome Parts of the Fleſh, which Mixture compoſes what they call a Muſcle, they then unite together again and make a *Tendon*, which generally is faſtened to ſome Bone.

6. How the Capillaments of the Nerves are ordered in a Muſcle.

6. Mr. *Steno*, a foreign Anatomiſt, has lately obſerved, that the Diſpoſition of the Capillaments of a Nerve which meet together in order to form a Muſcle, is very nearly like

Tab XVI. Fig. 2.

like what you fee reprefented in the Figure; where AB is the Nerve, BECF the Body of the Mufcle, and CD the Tendon. This being the Difpofition of the Capillaments of the Nerve, to which the Fibres of the Flefh correfpond, it is very evident, that if the Interftices GHILM be filled all at once with fome very fine Matter like Air; fuch as fhall afterwards be more particularly defcribed, and which Phyficians call *Animal Spirits*, the Capillaments, fuch as that reprefented by EC, muft be very much inclined to fuch Capillaments as that marked BE; and there will be a fmall Interval between B and C. But if the fame Interftices GHILM be empty, then the Capillaments, fuch as EC will grow ftraight again, and get clofe to each other, and fo by falling directly in with thofe that are like BE, they will make the Interval betwixt B and C larger.

7. Of the Head and Tail of a Mufcle.

7. It may be obferved here, that the Place of the Nerve marked B where the Mufcle begins, is called its *Origin*, and the Place marked D, where the Tendon is fixed to a Bone, or any other Part of the Body, is called its *Infertion*.

CHAP. IV.

Of the Heart.

1. Of the Fibres of the the Heart.

THE external Shape of the Heart is what no Body was ever ignorant of; fo likewife has it been always known, that the Flefh of it, is the firmeft, the moft folid, and the hardeft to be pulled in Pieces, of any of the whole Body. But it is very lately, that a curious Anatomift, (who thought of boyling a Heart, in order to the better and more eafily finding out the Difpofition of its Parts) obferved that the Fibres of its Flefh are difpofed two different Ways, fo that thofe which are on the out-fide go in the Form of a Screw from the Bafe to the Point; but thofe on the in-fide go more directly from the Bafe to the Point.

2. What Sort of Motion the Heart is capable of.

2. Now this different Difpofition of the Fibres of the Heart, may reafonably make us think, that the Heart is a *double Mufcle*, fo compofed, that if the Interftices which are betwixt the Fibres which go in the Form of a Screw, are filled all at once with a very liquid Matter, it muft grow

grow longer and narrower; but if these Interstices be empty, and those which are between the Fibres on the in-side, be filled; it must grow wider and shorter.

3. There are two *Cavities*, or *hollow Places* in the Heart which are separated from each other by a Piece of Flesh called the *Septum Medium*, or middle Partition. One of these Cavities is on the *right Side*, and the other on the *left*. They are each of them longer than they are broad; but the left Cavity is manifestly longer than the right one.

3. Of the Cavities of the Heart.

4. Each of these Cavities have two Holes at the Base of the Heart; at the Entrance into which Holes, there are particular Membranes so placed, that they will open and shut like Doors, though but one Way only. One of the Holes of the right Cavity, has three of these Membranes or Valves, so placed, that they will easily open to any Thing that would enter in; but shut themselves when any thing offers to come out: The other Hole has three Valves also, but placed the contrary Way to the former, so as to permit any thing that is within the Cavity to come out easily; but resist any Thing that would get in. One of the two Holes of the left Cavity, is not round like the rest, but oval, and has two Valves so placed as to open, when any Thing offers to enter into the Cavity, and to shut when it would go out; The other Hole has three Valves placed contrary to these last two, and will open to let any Thing, which is in the Cavity, go out, and shut to hinder any Thing from entering in.

4. Of the Apertures of the Heart and their Valves.

CHAP. V.

Of the Veins and Arteries.

THERE is scarce any Part of the Body but the Blood will come out at it if it be pricked; but there are some Vessels from which the Blood will flow in a large Quantity, if they be opened: These are like so many Channels to carry the Blood backward and forward; some of them consist of a very thin Skin which can easily be contracted, and we meet with a great Number of them under the Skin that covers the whole Body; these are called *Veins*: The other, which are composed of a very thick Skin, and don't

1. Of the Veins and Arteries.

don't lie so near the Superficies of the Body, are called *Arteries*.

2. That the principal Veins and Arteries end at the Base of the Heart.

2. The principal Veins and Arteries of the whole Body are four, which are inserted into the Base of the Heart, and so end at the four Holes which we just now mentioned.

3. Of the Vena Cava.

3. The Vessel which ends at that Hole of the right Cavity of the Heart where the three Valves are so placed as to let any thing enter in, is the Vein called the *Vena Cava*. It is hardly got from the Heart before it runs in amongst the Vertebræ, and is divided into two Branches which lie almost directly against each other. One of these goes upwards, and is again divided into an infinite Number of Branches which reach to the Arms and other superiour Parts of the Body, and is therefore called the *Vena Cava ascendens*. The other goes downwards, and is also subdivided into a very great Number of Branches which extend themselves to the Thighs and other lower Parts of the Body, and is therefore called the *Vena Cava descendens*. Thus all the Veins of the Body, except those of the Lungs and Heart, depend upon the *Vena Cava*, or are like Branches of which the *Vena Cava*, is the Trunk.

4. That the Veins of the Mesentery are Branches of the Vena cava.

4. Some have excepted the Veins of the Mesentery also; But because these unite in one Vessel, which is called the *Vena Porta*, which is inserted into the lower Part of the *Liver*, out of the upper Part of which comes the *Ramus Hepaticus*, which is united to the *Vena Cava* below the Place where it enters into the Heart; therefore the Veins of the *Mesentery* may be looked upon as Branches of the *Vena Cava*.

5. Of the Vena Arteriosa.

5. The Vessel that ends at that Hole of the right Cavity of the Heart, where the Valves are so placed as to open to any thing that would go out, is an Artery, which enters into and spreads it self all over the Lungs, and is there subdivided into an infinite Number of Branches of different Bignesses. The Ancients gave the Name of *Vena Arteriosa* to this Vessel, because they were prepossessed with this Notion, that they were only Veins that ended at the right Cavity of the Heart, and that all the Arteries ended at the left Cavity.

6. Of the the Arteria Venosa.

6. The Vessel which is at the left Cavity of the Heart, the two Valves of which will permit any thing to enter into that Cavity, is the Vein, which the Ancients by the same Mistake as before, called the *Arteria Venosa*, the Branches of which are also dispersed amongst the Lungs.

7. The fourth Veſſel, which is at the other Hole of the left Cavity of the Heart, where the Valves are ſo placed as to let any Thing go out, is an Artery called the *Aorta* or *Arteria-magna*. It enters in amongſt the Vertebræ juſt by the Heart along the Side of the *Vena-Cava*; and its Trunk, like that of the *Vena-Cava*, is divided into two Branches, which are ſubdivided and run in little Branches to all Parts of the Body in the ſame manner as the *Vena-Cava* does.

7. Of the Aorta.

8. Some Phyſicians have pretended to determine the Number of Veins and Arteries; but they could do it only in thoſe which are the moſt ſenſible; beſides which there are an infinite Number almoſt, which they call *Capillary*. And it ſeems very probable, that it is from ſome of theſe Veins that the Blood comes when any Part is pricked: From whence it follows, that the Blood is always contained in ſome Vein or in ſome Artery.

8. Of the Number of Veins.

9. The Antients taught, that there were a great many Places of the Body where the Veins and Arteries had a Communication with each other: Theſe Communications are what all Phyſicians call the *Anaſtomoſes*, ſome of which are to be ſeen ſometimes upon the Superficies of the Lungs: But, as to the reſt, which are a vaſt Number, as ſhall afterwards be ſhown, we may venture to ſay that the Ancients only gueſſed at them; the Foundation which they went upon being very weak, not to ſay abſolutely falſe; *viz.* There are, ſay they, *Anaſtomoſes*, that the Blood may paſs out of the Arteries into the Veins to give Life to them, and at the ſame time, that Blood may paſs out of the Veins into the Arteries to afford them Nouriſhment.

9. Of the Anaſtomoſes.

10. An *Engliſh* Phyſician, whoſe Name is *Harvey*, has lately diſcovered, that in a great many Places of the Veins, but eſpecially where any Vein divides into two Branches, there are little Valves to be found, which are ſo diſpoſed, as eaſily to open and afford a Paſſage to a Probe thruſt into the Vein, and puſhed from the extreme Parts of the Body towards the Heart; but they will reſiſt the ſame Probe, if we try to thruſt it the contrary way; *viz.* from the Heart to the extreme Parts of the Body.

10. Of the Valves of the Veins.

CHAP. VI.

Of the Lacteal and Lymphatick Veins.

1. *Some Precautions necessary, in order to see the lacteal Veins.*

THESE two Sorts of Veins were then found out, when live Animals were begun to be dissected. And there is some Precaution necessary in order to discover them. For the Animal must be made to eat two or three Hours before the Dissection is performed, otherwise the *lacteal Veins* will be empty and not to be seen.

2. *Of the Juice contained in the lacteal Veins.*

2. These Veins were first discovered by *Asselius*, and he called them *lacteal*, because they are white and contain a white Juice in them: They spread themselves all over the Mesentery, and mix themselves with those Veins which they just now said were Branches of the *Vena-Porta*: And if they be pricked, we see a Juice as white as Milk come out of them, which they receive from the Intestines, where we find the Extremities of their very small Branches begin.

3. *Of the Valves of the lacteal Veins.*

3. We also find some Valves in them, as in the other Veins of the Body, which are so ordered as to permit the white Liquor to run from the Intestines, but not back again to them.

4. *Of the Receptacle for the Chyle and the Channel of the Thorax.*

4. A Physician of my Acquaintance (Mr. *Pecquet*) has added to this Discovery another kind of *Receptacle* which is fixed to the Vertebræ a little above the Kidneys, which he has often shown me full of a Juice like that the lacteal Veins are filled with. He also was the first that observed a *Duct* which goes along the Vertebræ from this Receptacle to the Place where the Subclaviary Veins join with the *Vena-Cava*.

5. *Of the lymphatick Veins, and the Liquor contained in them.*

5. As to the *lymphatick* Veins, we cannot certainly tell who first discovered them. They are to be found, with a great deal of Trouble, in the Flesh of a live Animal. And though the Liquor contained in them, looks very much like Urine, yet it is certain that it has none of the Properties of it. For if it be put upon the Fire in a Spoon, it will grow thick and hard like the white of an Egg, which Urine will not do.

6. *Of the Valves of the lymphatick Veins.*

6. We do not know all the Turnings and Windings of the *lymphatick Veins*, nor how they are dispersed: But we observe Valves in them ordered like those in other Veins.

CHAP.

CHAP. VII.

Of the Tongue and salival Ducts.

ALL, both Ancient and Modern, who have treated of the Anatomy of human Bodies, have consider'd the *Tongue* as a Muscle: But it is but lately that the Structure of it was known. They who in our Days have had both Curiosity and Industry enough to make Enquiry into this Matter, have discovered in a boyled Tongue, that those of the Fibres composing it, which are near the Superficies, reach all the Way from the Root to the Tip; and that those which are within, are placed in several Ranks alternately, in which some of them go from Top to Bottom, and others go across. Whence it follows, that by some or other of these Fibres contracting themselves, the Tongue is moved all manner of Ways as we see it is.

1. Of the Fibres of the Tongue.

2. The *Spittle* does not fall into the Mouth, by an insensible Transpiration through the Pores of the Gums, as all the Ancients thought: There has lately been discovered *salival Ducts*, which resemble small Veins, and which end in the Inside of the Cheeks. These *Ducts* are large enough to put in a Hog's Bristle without any Violence; but because they are subdivided into lesser ones which become insensible, we know not where the Origin of them is.

2. Of the salival Ducts.

3. The Fluidity of the Spittle, will alone make it run into the Mouth; but sometimes it falls in a greater Abundance than at other Times: As, for Instance, when we chew any dry Victuals, or any Victuals that are somewhat hard: For then, every time we open our Mouth, and our Jaws remove further from each other, the Cheeks are stretched and compressed, so that they squeeze the *salival Ducts*, and force the Spittle out of them; And when the Mouth is shut, and the Cheeks reduced to their former State again, then they are filled as before.

3. The Reason why the Spittle flows into the Mouth.

4. Now because the Cheeks are very much compressed when we yawn, therefore a larger Quantity of Spittle than ordinary must then fall into our Mouths; and so we find by Experience, and that so manifestly, that if the *salival Ducts* be very full, it sometimes flies out of our Mouths to a considerable Distance.

4. Why the Spittle sometimes flies out of our Mouths when we yawn.



CHAP. VIII.

Of the LUNGS.

1. Of the Arteria aspera, and of the Lungs.

AFTER what has been before ſaid concerning the Lungs, there is nothing further neceſſary to be known: but only to obſerve here, that from that Part of the Mouth, where the Roots of the Tongue are, there deſcends a certain Channel which is called *Arteria-aſpera*, which is divided into ſo many Branches, that there is ſcarce any Part of the Lungs, be it ever ſo ſmall, but both they and thoſe of the *Arteria-venoſa*, and *Vena-arterioſa*, extend themſelves to it. So that it is not without Reaſon, that ſome have affirmed, that the Lungs are nothing elſe but a Texture made up of the Branches of theſe three Sorts of Veſſels

2. Why the Lungs are ſo light.

2. The *Arteria-aſpera* receives the Air which we draw in by our Breath; and becauſe it conſiſts of a very hard and ſtiff Membrane, it is always full of Air; and this is the Reaſon why the Lungs are ſo very light or weigh ſo little.

3. How the Uvula hinders any thing from falling into the Lungs.

3. The Victuals and Drink cannot get into the Throat without paſſing over the Mouth of the *Arteria-aſpera*; yet notwithſtanding nothing can ordinarily get into this latter, becauſe there is a kind of Valve, which they call the *Uvula*, which covers it every time we try to ſwallow any Thing. And if it does at any Time happen that a ſmall Piece of Victuals or a Drop of Drink do fall in; we are forced to cough it up again preſently.

CHAP. IX.

Of the LIVER.

1. Of the Liver.

WE do not find any ſenſible Veſſels in cutting the Liver; which is the Reaſon why we affirm the Liver to be a Heap of innumerable Veins not to be perceived, which the *Vena-porta* divides it ſelf into, and which ſeem

to

to be difperfed in this manner, in order to meet again and communicate with the *Hepatick Branch*.

2. The Liver, in the greateft Part of Animals, as well as in Man, is of a reddifh Colour. But there are fome Sort of Creatures whofe Liver is Green, others Yellow, and others of fome other Colour.

2 Of the Colour of the Liver.

3. We obferved a little before, that the *Bag of Gall* is placed in the lower Concave Part of the Liver; There is a fmall Tube which comes out of this Bag, and divides it felf into two Branches, one of which bends back and returns into the Liver again; but the other which is called the *Meatus* or *Canalis Choledochus* inferts it felf into the Beginning of the Inteftine called *Jejunum*, where it makes the Gall diftill through a Hole fo fmall that it is hardly to be perceived.

3. How the Vesicle of the Gall difcharges it felf.

CHAP. X.

Of the SPLEEN.

WE know nothing particular of the *Spleen*, but only that it is full of very grofs Blood, and that it has a Communication with the Ventricle by Means of a fmall Duct which Phyficians call the *Vas-breve*; and with the Heart, and fome other neighbouring Parts by Means of fome Arteries and Veins.

1. Of the Blood contained in the Spleen.

2. I faw a Dog once whofe Spleen had been taken out fix Months; the Wound neceffary for this Operation, having been few'd up, healed by Degrees, and the Dog recovered his Strength again in Proportion; fo that at laft there appeared no external Sign of any Inconvenience that the Dog fuffered for want of it.

2. That the Spleen is not abfolutely neceffary to Life.



CHAP. XI.

Of the Kidneys and Bladder.

1. Of the Substance of the Kidneys, and of their Basons.

THE Substance of the *Kidneys* seems to be of the Nature of a very fine Sponge, and we see in each Kidney a certain Cavity which they call a *Bason*, and which is always almost full of Urine.

2. Of the Vessels near the Kidneys.

2. It is also to be observed here, that each Kidney is placed at the Extremity of the *emulgent* and *Artery Vein*.

3. Of the Ureters.

3. The two Kidneys have a Communication with the *Bladder* by two very slender Ducts, called the *Ureters*, which are generally full of Urine, and where we sometimes find small Stones like those generated in the Kidneys: They are inserted into the Bladder somewhere about the Neck of it, but the Passages whereby the Urine gets into it are so small that they cannot be perceived.



CHAP. XII.

Of the Motion of the Blood.

1. The Opinion of the Ancients concerning the Motion of the Blood.

THE *Motion of the Blood* is one of those Things which I said before could not be known by the Help of Reason. And it is a famous Question amongst Physicians, and what they are very much divided about; *viz. Where the Blood is made,* and *how it is moved:* The Ancients, whose Opinions the greatest Part of our old *Doctors* follow still, thought that all the Blood came from the *Liver*; and because only a small Part of it goes into the *Vena-porta*, and from thence into all the Branches of it; therefore the greatest Part of it, passes into the *Vena-cava* and so into all the Branches belonging to it; but in such a Manner, that at the coming out from the *Liver*, a considerable Quantity of it, turns about and enters into the *right Cavity of the Heart*, where it is divided into two Parts, one of which runs through the *Vena-arteriosa* into the *Lungs*, and the other through the *Medium-septum* into the *left*

left Cavity; where, they say, it is converted into *arterial Blood* or *vital Spirits*, which is carried into the *Lungs* by the *Arteria venosa*, and all over the Body by the *Arteria magna* and its Branches.

2. That the Blood according to the Opinion of the Ancients moves very slowly.

2. According to this Opinion, the Blood always moves from the Middle of the Body to the extreme Parts, without ever returning back again; And since it is asserted, that it advances forward only in Proportion as the Parts get out of the Veins and Arteries to nourish the Animal; it follows, that the Motion of the Blood must be very slow.

3. A Confutation of this Opinion.

3. This Opinion was received from the Ancients, without any Proof, at a Time when no Body suspected that the first Philosophers were capable of any Mistake: But since we do not submit so blindly to *Authority* in such Matters as these, we find that this Opinion is only mere Imagination without any Ground, and that it ought to be utterly rejected: For besides its making the Blood pass through the *Septum* of the Heart, where there does not appear to be any sensible Pores, and where we find by Experience, that neither Air nor Water will pass through, it does not at all agree with the Position of the Valves which are at the Entrance of the *Arteria-venosa*, and a great many other Places of the Veins. Not to spend any further Time therefore, nor to amuse our selves in confuting this Opinion, I shall content my self with endeavouring to establish another Conjecture, the Reasons for which appear to me so plausible, that I hope there will be no Difficulty in admitting it, when we have once been at the Trouble to examine it.

4. That the Blood enters into the Heart from the Vena-cava and Arteria-venosa.

4. If we remember the Disposition of the Valves which are at the two Holes of the Heart, where the *Vena-cava* and *Arteria-venosa* end; we shall see, that these two Vessels being always full of Blood, there must necessarily flow out of each of these one great Drop of Blood, into each Cavity of the Heart when it is empty.

5. That the Blood passes out of the Cavities of the Heart into the Vena-arteriosa, and Aorta.

5. These two Drops being dilated by the Heat which is in the Heart, which is greater than in any other Part of the Body, as we find by Experience, endeavour to go out at the Holes which are in these two Cavities; but because they cannot get out at those through which they entered in, they themselves stopping up the Passage that Way by pressing against the Valves at the Entrance; therefore they must go out at two other Holes where they can open the Valves: And thus almost all the Blood which is in the right Cavity, passes into the Lungs through

the *Vena-arteriosa*, and almost all that which is in the left Cavity passes into the *Aorta*.

6. That there flows Blood again out of the Vena cava and Arteria-venosa into the Cavities of the Heart.

6. The Blood which is thus got out of the Heart cannot enter in again, because the Valves are so placed that it stops up the Passage it self. Wherefore that which remains in the Cavities of the Heart, being no longer able to press against the Valves which are at the Holes where the *Vena-cava* and *Arteria-venosa* end, there must again fall in two other great Drops of Blood, which dilating themselves as the former, go the same Way as they did.

7. That the Blood passes out of the Arteries into the Veins.

7. Now in Order to see how it is possible for this to continue during the whole Life of the Animal, we must consider, that every Time the *Vena-arteriosa* receives the Blood that is newly dilated in the *right* Cavity of the Heart; this Blood impells that which the Vein was filled with before, so as to make it discharge some Part of it self into the *Arteria-venosa*, which it passes into not only through those visible Anastomoses, which we mentioned just now; but also through an infinite Number of insensible Passages, which are at the Extremities of the Branches of the *Vena-arteriosa*, and which end at the Branches of the *Arteria-venosa*. So likewise we must consider, that every Time the *Aorta* receives the Blood that is newly dilated in the left Ventricle of the Heart, this Blood presses upon that which it was filled with before, and makes it discharge part of it self into the Branches of the *Vena-cava*, which it gets into through some Anastomoses that are visible, and through an infinite Number that are invisible.

8. Of the Circulation of the Blood.

8. This being so: The Blood which is in the Veins moves from the extreme Parts of the Body towards the Heart, which it enters into through the *Vena-cava* which discharges it self into the *right* Cavity of the Heart; from hence it goes into the *Vena-arteriosa*, then into the *Arteria-venosa*, and from thence into the left Cavity of the Heart, from whence it is carried to the extreme Parts of the Body, through the Trunk and Branches of the *Aorta*, the Ends of which are united with those of the *Vena-cava*, so that these latter send the Blood back again to the Trunk belonging to them, which afterwards discharges it into the *right* Cavity of the Heart. And thus that famous *Circulation* of the Blood is made; for the Discovery of which we are obliged to Dr. *Harvy*.

9. That the Circulation of the Blood is confirmed by

9. Having thus seen, that the Circulation of the Blood is a necessary Consequence of the Disposition of the Vessels, which contain it; there are two very strong Arguments

Arguments by which it may be further confirmed. *First*, if the Skin of any live Animal be ript in any Part where there is a pretty large Vein, and this Vein be so freed from the Flesh that is about it, as it may be tied close up by a Thread going round it; we shall see that Part of the Vein, which is betwixt the Ligature and the Heart, grow empty; and on the contrary, that Part which is betwixt the Ligature and the extreme Parts of the Body will swell. And if this Vein be pricked, or if it be cut in two, betwixt the Ligature and the Heart, there will come out but very little Blood; whereas if it be only pricked betwixt the Ligature and the extreme Parts of the Body, there will come out such a Quantity of Blood that the Animal may die: Which is a certain Sign that the Blood does not move in the Veins *from the Middle of the Body to the extreme Parts*, as the Ancients thought; but on the contrary, that it moves *from the extreme Parts of the Body to the Middle.*

the Experiment of Ligatures.

10. It is easy to see that what is thus done in Beasts, is in like Manner, done in Men, if we consider the Method of letting Blood. For since the Surgeons are obliged to tye up the Arm, in Order to make the Blood come out of the Vein at an Orifice below the Ligature; we cannot reasonably think otherwise, but that the Ligature, which the Arm is tyed with, by compressing the Veins, but not compressing in the same Manner the Arteries, which are not so supple, and which lie deeper under the Skin, will permit the Blood to run along the Arteries of the Arm, from the Middle of the Body to the Ends of the Fingers; but that it will not permit it to return again from thence so freely, through the Veins to the Middle of the Body, because this Ligature it self stops it, so that the Blood is forced to go out at the Orifice they make.

10. Of the Method of letting Blood.

11. And this will appear still more evidently, if we consider that, when the Arm is bound up so hard that the Arteries are compressed, it is impossible to get any Blood out at the Orifice of the Vein, without first loosening the Ligature, in Order to give Room for the Blood to move in the Arteries beneath.

11. Why sometimes the Ligature must be loosened, that the Blood may come out.

12. Another Argument which confirms the Circulation of the Blood, in the Manner we have now described; is an Experiment made in some of the Veins which are just under the Skin, and are the most visible of all. If we take any single Branch of one of these Veins, as for Instance, one of them which are on the Back

12. Another Argument to prove the Circulation of the Blood.

Tab. XVI. Fig. 3.

Back of the Hand, which is here reprefented by AB, of which A is the Part fartheft diftant from the Heart, and where two Branches unite in one; and B the Part neareft the Heart, and where the Branch divides again into two other; If, I fay, we prefs the Vein at A with the End of one of our Fingers fo as to ftop the Blood, and at the fame Time flide another Finger along the Vein AB, to drive the Blood towards CC; then the Vein AB will be emptied and difappear; neither can the Blood be made to get again into it by moving the Finger from C to B, becaufe there is a Valve at B which ftops it. But that which evidently proves fuch a *Circulation* of the Blood as we have defcribed is this, that if the Part B be preffed with the Finger, fo as to hinder any Blood going towards the Heart from B to A, and the other Finger be taken off from A, you will have the Pleafure, to fee the Branch AB filled immediately with Blood, and the Blood will move from A towards B, that is, from the extreme Parts of the Body towards the Middle.

13. *A Demonftration of the Anaftomofes of the Veins and Arteries.*

13. There is a particular Demonftration of the invifible *Anaftomofes*, or Communication between the Extremities of the Arteries and the Extremities of the Veins. If the Breaft of a live Animal be cut open, and the Aorta tyed up at two Inches Diftance above the Heart, and then cut in Pieces betwixt the Ligature and the Heart; the Confequence will be, that not only all the Blood in the Veins, but that in the Arteries alfo will in a very little Time run out at that Hole in the Heart whereby the Blood ufes to pafs out of the left Cavity into the Aorta: Which it could not do, if the Extremities of the Branches of this Veffel, had not a Communication with the Extremities of the Branches of the Veins.

CHAP. XIII.

Of the Pulfe, or Beating of the Heart and Arteries.

1. *That the Motion of the Heart and Arteries depend upon the Blood.*

THE Beating or Motion of the Heart and Arteries, which is called the *Pulfe*, is fufficiently known by Experience; the Difficulty lies in finding out how it is done. But becaufe this Motion is nothing elfe but a Sort of

of Dilatation in the *Heart and Arteries*, which is made regularly, and in such Measure, that the Arteries beat neither faster nor slower than the Heart; I can't but think, that both the *one* and *the other* depend upon the same Cause, and that this Cause is no other than the Alteration of the Blood made in the Heart.

2. How the Blood causes this Motion.

2. It is probable therefore, that every Time any Blood gets into the two Cavities of the Heart, this Blood mixes with that which was before left in it, which serves like Leaven to make it dilate all at once; by which Means, the Heart it self is also forced to dilate and grow broader: After which, when the greatest Part of the Blood which was in these Cavities goes out, *viz.* that of the *right* Cavity, into the *Vena-arteriosa*, and that of the *left* Cavity into the *Aorta*; then the Heart relaxes and grows long again; and it is in this continual Alteration of the Figure of the Heart that its Beating consists: And as to the Arteries; their Motion consists in this, that they swell upon receiving fresh Blood from the Heart; and return to their first State again immediately upon the Blood's losing its Force and Agitation.

3. That the Fabrick of the Heart contributes to this.

3. Not that I am unwilling to confess, that the Heart is disposed, by the Fabrick of it, to dilate and contract it self another Way: For it being composed of two Muscles, it is reasonable to think, that they exercise their Power alternately, that is, the Animal Spirits pass by Turns out of one Muscle into the other. However, I am of Opinion that it is the Dilatation of the Blood in the Heart which regulates their Power; because the Heart dilates it self quicker or slower, according as the different Qualities of the Blood, make it capable of a quicker or slower Dilatation.

4. Why the Heart beats after it is taken out of the Body of an Animal.

4. This second Cause of the Motion of the Heart, being supposed; it is no more strange that it should sometimes beat, after it is taken out of the Body of a live Animal, than that a *Bell* should continue to move, after we have let go the Rope; Neither can there, I believe, be any other Reason given for it than this.



CHAP.

CHAP. XIV.

What Time the Blood circulates in.

1. How to calculate the Time of the Circulation of the Blood.

BY reckoning very nearly the Quantity of Blood which passes into the Aorta at every beating of the Heart, and by determining also the Quantity of Blood which there is in the whole Body; we may find how long Time it takes to finish one Circulation, by some such Way of Reasoning as this. First then, I am of Opinion, that every time the Heart beats, it throws a Drachm of Blood into the Aorta, which is the least, I think, that can cause a sensible Dilatation in all the Arteries: This being supposed, I count how many times my Pulse, and consequently my Heart, beats in a *minute* of an Hour, and I find it beats sixty four times, that is, three Thousand eight Hundred and forty times in an Hour: Whence I conclude that there passes through the Heart every Day, ninety two Thousand one Hundred and sixty Drachms of Blood, which make eleven Thousand five Hundred and twenty Ounces, or seven Hundred and twenty Pounds of Blood. Wherefore if I had so much in me, I should conclude that it circulated once a Day; but because I am of Opinion that there is not above ten Pounds of Blood in my whole Body; I conclude that in twenty-four Hours, it passes seventy-two times through the Heart, and consequently the whole Blood circulates three times in an Hour.

2. That this Computation may not be very exact.

2. But it is very manifest, that if more or less Blood than I have supposed, goes out of the Heart at every Beating, if the Pulse be faster or slower than I found mine to be by Experience, or if the whole Mass of Blood be not just ten Pounds as I imagine it to be; there will be found a different Number of Circulations in an Hour, than what I have laid down; so that the Calculation now made, serves only for an Example to make others by.

CHAP.

CHAP. XV.

Of natural Heat.

THERE is a certain *Heat* in us which is not transient, like that impressed upon inanimate Subjects by Fire, but which continues in the Depth of Winter, and lasts as long as we live; this is what we call *natural* Heat: Concerning which there have been two Things which Men have always been sollicitous to enquire into. First, What it consists in; and secondly, How it is communicated from the Heart, which is as it were the Center of it, to the most extreme Parts of the Body.

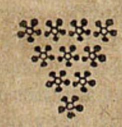
1. What natural Heat is.

2. It seems to me most probable that natural Heat owes its Original to the Blood, and is pretty much like that we mentioned in the first Part of this Treatise, which arises from the Mixture of two Liquors; for Instance, of Oyl of *Tartar* and Oyl of *Vitriol.* For after the greatest Part of the Blood which is rarified in the two Cavities of the Heart, is got out through the *Vena-arteriosa* and *Aorta*; that little Blood which still remains in those two Cavities, and that new Blood which comes from the Bags or Ears of the Heart, are like these two Liquors, and one of them serves as Leaven to the other, to dilate and heat it.

2. What it consists in.

3. As a Consequence of this, it is evident; that the Heat communicates it self to all the Parts of the Body by the Blood which comes to them perpetually from the Heart through the Arteries. Thus we perceive the Heat to be proportionably greater, when the Pulse of the Heart and Arteries is quicker, and the Blood has not time enough to cool, because it is so soon carried from the Middle of the Body to the extreme Parts.

3. How it extends to all the Members.



CHAP.

CHAP. XVI.

Of Nourishment and Growth.

1. That the Parts of our Body are continually altering.

ALL the Parts of our Bodies, except the Bones, being very soft; it seems to me very reasonable to think that they are continually wasting, and that this Wasting is increased by the several Motions of our Members, and by the Action of those external Things which surround us: Yet we can scarce perceive any sensible Diminution in our Bodies, especially if we be in perfect Health; nay, we sometimes find, on the other Hand, that they increase and grow bigger in a very little Time: Whence we must easily be convinced, that some new Substance must come into the Place of that which we are continually losing, and that this contributes to our growing bigger. Thus we see, that if any small Hurt happens to almost any Part of our Bodies, they heal, as it were, of themselves; and that when any small Part of the Skin or Flesh dies, and comes off from the Body, another comes in its Room, and the Part which was hurt, becomes at last like the other Parts, or like what it self was before.

2. What is meant by Nourishment and Growth.

2. When the Particles which are changed into the same Nature as our Body, make it only to continue in the same State, this is called *Nutrition*; but when they are applied in so great a Quantity, and of such a Sort, that they increase the Bulk of it, this is called *Growth*.

3. That Nutrition and Growth are made by the Blood.

3. In order to explain how this Alteration is made; all the ancient Physicians, and some of the modern ones, who hold that Opinion concerning the Motion of the Blood which we have confuted, teach; that the Blood when it is got to the Extremities of the Branches of the capillary Veins, comes out of them and changes it self into a kind of Dew, which afterwards thickens, like moderately thick Glue, and then the several Parts of the Body divide it amongst themselves, every one attracting to it self that which it wants, and converting it into its own Nature. Thus the Flesh attracts one Part, which it turns into Flesh, and the Bones another Part, which they convert into Bones, and this they do by an occult Vertue, which they call the *Attractive or assimilating Vertue.*

4. But

4. Wherein this Notion is defective.

4. But ſince this Opinion appears contrary to Reaſon; becauſe it does not at all agree with what was above demonſtrated concerning the Circulation of the Blood; nor does it in the leaſt explain how the venal and arterial Blood are converted into Dew, and then into Glue; and becauſe it ſuppoſes, that every Part of the Body is endued with an *attractive or aſſimilating Vertue*, which is what I do not at all underſtand; therefore I think my ſelf obliged to enquire after another Explication of this Alteration.

5. How Nouriſhment and Growth are perform'd.

5. In order to which, we need only to conſider in what State the Blood is when it comes out of the Heart to fill the Arteries: For it being then very much thinned and dilated, and impelled all Ways with great Violence; we cannot but think, in the firſt Place, that ſome ſmall Part of that which runs into the *capillary* Arteries, gets out of them through an infinite Number of Pores, which are in the Skins of which they are compoſed, and which open themſelves at every Pulſe; Further, if we conſider alſo, that theſe Pores are ſo ſtrait, as not to ſuffer freely all the Parts of the Blood that go through them to move all Ways indifferently; we ſhall conclude, that they are carried but one Way only; ſo that by following one another and at the ſame time touching each other, they compoſe not a liquid, but ſmall Threads only, like the Fibres of Fleſh: And thus *Nutrition* is made, when that which waſtes at one Extremity of the Fibres of the Fleſh, is repaired by an equal Quantity of Matter joining or uniting it ſelf to the other Extremity, and impelling or driving the Fibres before it; And *Growth* is performed, when more new Matter is added than is waſted away of the old.

CHAP. XVII.

Of the Animal Spirits, and of the Motion of the Muſcles.

1. That there are Animal Spirits.

BESIDES thoſe ſenſible Parts of our Body which we have taken Notice of, there is yet another Sort of Matter not to be perceived by the Senſes, which is like very fine and much agitated Air, and which Phyſicians call *Animal Spirits*. That there are ſuch cannot be doubted,

ed, if we confider, that a great many Parts of our Bodies will fwell all on a fudden, where there is not the leaft Sufpicion of the Blood running in to produce fo quick an Effect: Now this cannot well be afcribed to any Thing elfe but to a very fine and very much agitated Matter.

2. The Doctrine of the Ancients about Animal Spirits was defective.

2. The Ancients thought, that the Animal Spirits were made out of fome of the Arterial Blood, which getting through the *Carotides* into the Brain, they imagined that the Subftance of the Brain had a Power to convert this Blood into Spirits. But we muft acknowledge that this Doctrine is very obfcure and defective, becaufe it does not fhow us what this Power confifts in, nor what the particular Nature of thefe Animal Spirits is.

3. How the Animal Spirits are produced; and that the Brain ferves only to feparate them from the reft of the Blood.

3. That we may make this matter more intelligible, let us confider, that the Blood being heated and dilated in the left Cavity of the Heart; fome of its Parts, by dafhing againft each other, muft be made fubtler in fuch a manner, and acquire fuch Sort of Figures, as will enable them to move more eafily than others, and to pafs through fuch Pores as the other will not pafs through. Thefe moft fubtle and moft agitated Parts come out of the Heart along with thofe which are not fo fubtle nor fo much agitated. And the Difpofition of the Aorta is fuch, that whatever goes out of the left Cavity of the Heart tends directly to the Brain; but becaufe there is a very great Quantity of thofe Particles, and becaufe the Paffages of the Brain are too ftrait to receive them, therefore the greateft Part of them are forced to turn and go another Way; and the fineft and moft agitated Particles only can enter into the Brain, where they are made ftill finer and feparated from thofe which are not fo fine. Now it is thefe Particles, which are made thus fine and feparated from the groffer Particles, that they call *Animal Spirits*, to the producing of which the Brain no otherwife conduces, but only like a very fine Sieve, that feparates the fineft Flower from the Coarfe.

4. What the Motive Power of the Mufcles confifts in.

4. After we are once convinced that there are Animal Spirits, and are affured that the Brain is the Receptacle of them; there is nothing obfcure in what they call the *motive Faculty* or the Principle of the feveral Motions of the Members: For it is eafy to apprehend, that when either the particular Figure and Agitation of the Particles which compofe thefe Spirits, or the external Objects which affect the Organs of our Senfes, or our own Inclination to fuch or fuch Motion, determines into what Nerve thofe Spirits fhall enter rather than into any other; they will

ſooner enter into that particular Nerve than any other; which conſequently, from the common Structure of all the Muſcles, will ſwell and grow ſhorter, and then the *Tendon* muſt draw up that Part of the Body to which it is fixed; and in this manner it is that our Members are moved.

5. Nor is it neceſſary, that every Time we move any one of our Members, the Brain ſhould ſend a large Quantity of new Spirits into the Muſcle which ſerves to produce this Effect: For each Member being capable of being moved two contrary Ways, by the *Muſcles* called *Antagoniſts*, we muſt think, that when the Muſcle which ſerves for one of the Motions, ceaſes to act; the Spirits which ſwelled it, paſs into its Antagoniſt by a Duct common to them both, and ſo helps to move the Member: And in order hereunto, there is no need of any more Spirits flowing from the Brain, than is neceſſary to open and ſhut the Paſſages of this Duct conveniently, and to ſupply thoſe Spirits which are ſo attenuated by continual Agitation, that loſing the Nature of Spirits, they fly off through the Pores of the Membrane in which each Muſcle is contained.

5. That there are not many new Spirits required for any particular Action.

CHAP. XVIII.

Of RESPIRATION.

IF to what was obſerved in the firſt Part of this Treatiſe, (namely, *That Reſpiration depends upon the Action of the Muſcles of the Breaſt and lower Belly, which by ſwelling or making flat the Body, makes the Air to enter in or go out*;) we add, what was now ſaid concerning the Action of the Muſcles; we ſhall have cleared all that one would deſire to know upon this Subject.

1. How Reſpiration is performed.

2. However, I cannot omit one Particular, which though of no great Moment, is yet worth obſerving; and that is, that when our Mouth is open, we can at Pleaſure, either breath through our Noſtrils without breathing through our Mouth, or breath through our Mouth without breathing through our Noſtrils. Now in order to ſee the Reaſon of theſe two Effects, we muſt obſerve, that

2. Why when our Mouth is open, we can breath either through our Mouth or Noſtrils.

the firſt depends upon this, that we can ſo draw back our Tongue to the Bottom of our Mouth, as to hinder the Air from entering into the Lungs that Way, as much as if the Mouth were quite ſhut; and ſo it is forced to enter in through the Noſtrils. The ſecond depends upon this, that we can make ſome Pieces of Fleſh, which are at the Bottom of the Noſtrils on the Inſide, and which are like Muſcles, come ſo cloſe together, that the Air not being able to get into the Lungs that Way, is forced to enter in by the Mouth.

3. The Uſe of Reſpiration.

3. The Neceſſity of Reſpiration appears ſufficiently in moſt Sorts of Animals, which die if it be ſtopped for any time; And for the Uſe of it, it is very probable, that the Air, by getting into the *Arteria-aſpera*, cools and condenſes the Blood which runs along in the Branches of the *Arteria-venoſa*, in order to make it fit Fewel for that Sort of Fire which is in the left Cavity of the Heart, and that it may be there dilated again: And this ſame Air, when it comes out of the Body and the Lungs, brings along with it certain Parts which are purged off from the Blood as it runs in the Branches of the *Vena-arterioſa*, and *Arteria-venoſa*, which are as it were the Smoak or Soot of the Blood.

4. A notable Obſervation of what ſupplies in the Fœtus the want of Reſpiration.

4. Infants don't breath at all whilſt they are in their Mother's Womb; and the Blood which is once heated in the right Cavity of the Heart, not being cooled by Reſpiration, cannot be proper to nouriſh that Fire which is in the left Cavity: Wherefore Nature has provided againſt this, by ſo ordering it, that the Blood when it is once heated and dilated in the Heart, ſhould not enter into it again, except perhaps in a very ſmall Quantity: For, the greateſt Part of the Blood which goes out of the right Cavity of the Heart, paſſes immediately out of the Trunk of the *Vena-arterioſa* into the *Aorta*, whilſt other Blood to ſupply the Defect of this, paſſes immediately out of the *Vena-cava* into the Trunk of the *Arteria-venoſa*, from whence it flows into the left Cavity of the Heart and is there dilated.

5. How thoſe Birds which dive into the Water, can continue a long time without breathing.

5. The Holes or Channels through which the Blood paſſes in this manner in Children before they are born, are ſtopped up by Degrees after they are born; becauſe they being then able to reſpire, the Blood which comes out of the right Cavity of the Heart, is ſufficiently cooled and condenſed before it enters into the left Cavity to nouriſh the Fire which is there. The ſame Thing happens to the greateſt Part of Beaſts; whereas in Men, for want of

Use, these Channels are stopped up, so that in six Weeks, or two Months after they come into the World, there does not appear any Hole or Ducts at all. But because there are some Animals, such as *Ducks* and *Cormorants*, which will sometimes continue a long while under Water, where they seek for Food, and where they cannot breath; in such Creatures, the Holes now mentioned are not stopped up, but they make use of them all their Lives; which is owing either to their constant using of them, or else to the particular Nature of such Animals, whereby it is harder for them to close and be stopped up.

6. Of the famous Divers of old.

6. And perhaps those famous Divers amongst the Ancients, concerning whom Historians relate, *That they continued whole Hours under the Water to the Admiration of all*, were of such a wonderful Constitution of Body peculiar to them, that their Blood kept open those Passages, that it might run in them when there was Occasion, as it did before they were born, and as it does in the Bodies of Ducks and Cormorants.

CHAP. XIX.

Of Waking and Sleeping.

1. Of Waking and Sleeping.

THAT which Experience principally teaches us concerning *Waking*, is, that we are then in such a State, as to hear the Words of those that speak to us, to see the bright Objects that are before our Eyes; in a Word, we then perceive, in all the several Ways that we are capable of perceiving, when any Objects act with sufficient Force upon the Organs of our Senses. To which we may add, that we can then move our Bodies also several Ways just as we please. And *Sleep*, we find by Experience, to be a State opposite to this, in which the common Actions of external Objects upon the Organs of our Senses, do not raise any Sensation in us, and during which our Bodies appear to be at perfect Rest.

2. What being awake consists in.

2. In order to account for these two States, it is sufficient to consider, that Waking consists in this; that the Animal Spirits being at that Time in great Plenty in the Brain, and capable of being easily determined to run from

thence through all the Nerves, they fill them in ſuch a manner as to keep all the Capillaments of them ſtretched, and diſtinct from each other. For, upon this Suppoſition, it is eaſy to apprehend, that if any Object affects any Part of our Body, the Capillaments of the Nerves which end in this Part can tranſmit the Impreſſion which they receive, to that Place in the Brain which immediately excites a Senſation in the Soul. It is alſo eaſy to conceive, that the Animal Spirits, being then ſent into ſeveral Muſcles, make the Parts of the Body into which thoſe Muſcles are inſerted, to move ſeveral Ways.

3. What Sleep conſiſts in.

3. A State of Sleep being oppoſite to that of Waking, in order to determine what it conſiſts in, we need only ſuppoſe a different Diſpoſition in the Brain from that which cauſed Waking. And as that conſiſted in the Quantity of Spirits; the other, for the contrary Reaſon, ought to be cauſed by a Scarcity or Failure of Spirits; ſo that the Pores of the Brain, through which the Spirits uſually run into the Nerves, not being kept open by the continual flowing of the Spirits, ſhut up of themſelves. The Conſequence of which will be, that the Animal Spirits, which were in the Nerves before, being diſſipated, and no new ones flowing in, the Capillaments of the Nerves will become ſlack and ſoft and cleave to each other. And if at that time any Object makes an Impreſſion on any Part of the Body, thoſe Nerves cannot tranſmit it to the Brain; whence it follows, that there can be no Senſation: Further, the Muſcles, which are then void of Spirits, being relaxed, are of no uſe to move the Members into which they are inſerted; nor can they any more contribute to keep the Body in any particular Poſture, than if they were entirely deſtroyed.

4. How Sleep may be voluntary.

4. The Cloſing of the Pores of the Brain, which are the Orifices of the Nerves, and conſequently Sleep, follows neceſſarily from any great Loſs of Spirits: But if there be a ſufficient Quantity of Spirits in the Brain which may be employed, if we make but a ſmall Effort, to the Actions of Waking, and we do not employ them; the Beginning of ſuch Sleep may be ſaid to be voluntary. For thus we ſee, that a Perſon who finds himſelf diſpoſed to Sleep, can forbear Sleeping for ſome time, if he will, by applying himſelf intently upon doing ſomething, and employing his Animal Spirits, which otherwiſe would be imployed another Way, to Actions which ſerve to keep him awake.

5. Since

5. Since the Animal Spirits are in very great Agitation, it is easy to imagine, that if they are not employ'd in keeping us awake, but remain in the Blood, they must increase the Agitation of its Parts. And because the Increase of the Heat of the Blood and of that of all the Members, consists in this; it follows, that if we sleep in a Bed in the Depth of Winter, we grow warmer than if we keep our selves awake.

5. Why we grow warm by Sleeping.

6. It may happen, that while we are asleep, some of the Animal Spirits which are in the Brain, may shake some of the Parts of the Brain, in the same manner as they would be shaked by an external Object affecting the Senses of the Body. And in this Case, there will be a Sensation raised in the Soul, and such a Sort of Perception as we call a *Dream*.

6. The Cause of Dreams.

7. And because those Parts of the Brain which are used to be shaken by the Action of some external Object upon them, are more easily agitated than those which are always at rest; therefore these are commonly put in Motion by the Animal Spirits when we are asleep; which is the Reason why we scarce ever dream of any Thing in our Sleep, but what we have seen when awake.

7. Why we never dream of any thing but what we have seen when awake.

8. And because that great Variety of Objects which we have taken Notice of in the Course of our Lives, hath agitated the Parts of the Brain in very different Manners; it would be a Wonder, if in our nightly Dreams, the Animal Spirits should at any Time move them otherwise than as if partly one Object were present, and partly as if another were present; And thus the Perception raised in the Soul, may sometimes be *the Head of a Lyon upon the Body of a Goat*; that is to say, it is very hard for our Dreams to be at any time regular and orderly.

8. Why Dreams are generally disorderly.

9. The Nature of Sleep being such as we have now described; it is evident, that it may be interrupted, if any of our Organs of Sense be so shaken, that the Impression made upon it, extends to the Brain: For in this Case, those few Animal Spirits which remain in the Brain, and those which flow thither without Interruption, may be employ'd to drive away Sleep.

9. How any one may awake from Sleep.

10. But if no Object should act thus strongly upon the Organs of the Senses, yet Sleep must necessarily end after a certain Time. For the Animal Spirits which are produced in Sleep, will in Time become so plentiful, that they will be able of themselves to open the Orifices of the Nerves, and to fill them so much as is necessary to disengage the Capillaments, and make them occasion the Soul to feel Objects which touch the Body. Thus a Man

10. Another Cause of awaking from Sleep.

that is asleep in his Bed, may be awaked by the Sensation which is raised in him by the Hardness of the Mattress on which he lies, or by the Sheets being ruffled ; or, as it very often happens, by the Sensation or Motion which we may have to go to Stool.

CHAP. XX.

Of the Concoction of MEAT.

1. That the Blood is made out of the Food.

SINCE some Part of the Blood is perpetually converted into Animal Spirits, as was just now explained; and a much more considerable Part is employed to nourish or augment the Body, it must necessarily at last be all dried up, if there were not a Supply of new. Further, every one knows, and the continual Appetite which we have for Food, does moreover show, that it is *that* which supplies this Loss, and furnishes this Want, by being changed and converted into Blood; but it is not so easy to tell how such a wonderful Change is made.

2. The Opinion of the Ancients about Concoction.

2. Daily Experience teaches us, that after the Victuals are in a gross Manner ground, bruised, and divided by the Teeth, and moistened with the Spittle, they go down into the Stomach, where they continue to be divided into still smaller Parts. This second Division, which so alters the Condition and Form of the Food that we don't know it again, is what we call *Concoction*, which the Ancients thought was performed by the Heat of the Ventricle only.

3. The Fault of their Opinion.

3. We may venture to affirm, that the Ancients would not have taught this Opinion but for want of a better : Not that it appeared to them defective for want of sufficient Proofs; for the Authority of them that advanced it, was an undeniable Proof according to the Custom of those Times, when, in order to establish any Opinion, it was sufficient to say, that such an one was the Author of it. But that which created a Difficulty, even to them, was; that they saw a great many Animals, in whose Ventricle they could not observe any Heat; as for Instance in Fishes, which notwithstanding did not want Concoction, nay, had as good a one, as those where the Heat is greatest of all. Wherefore, that they might not be at a stand, at a Time when Philosophers had the Vanity to declare, that there was not

not any Thing that they did not underſtand; they found out a Way to get rid of this Difficulty, by ſaying, that the Heat which ſerved to concoct Food, was a particular extraordinary Heat, not at all like that which we perceive by our feeling. But this is a meer Sophiſm; for it ſignifies no more than to ſay, that the Concoction of Food is caufed by ſomething we do not at all know what, which we call Heat.

4. That the Miſtake of the Ancients might appear more plain, I have oftentimes made the following Experiment. I procured a certain Quantity of thoſe ſmall Bones which are at the extreme Parts of thoſe Sheeps Feet which they ſell about half boiled; Part of theſe I put into a Pot almoſt full of Water, and boiled them over the Fire for near three Hours; after which the Bones did not appear to be at all changed; I gave the other Part of them at the ſame time to a great Dog, who devoured them immediately, and in three Hours I found theſe Bones almoſt entirely concocted. Now the contrary ought to have happened, if the Concoction had been cauſed by the Heat only; for the Heat in the Pot was much greater than that in the Dog's Stomach: Hence we may conclude, that Concoction is not performed in the manner the Ancients taught.

4. That Concoction is not performed by the Heat of the Stomach only.

5. The modern Chymiſts have paved the Way to the Diſcovery of this Truth. For they have ſhown in the firſt Place, that Liquids are the moſt effectual Cauſes of the Diſſolution of hard Bodies; and that there are ſome Sorts of *Aqua-Fortis* proper to diſſolve ſome Bodies, and other Sorts proper to diſſolve other Bodies. It is therefore very reaſonable to think; that after the Food has been bruiſed and divided in the Mouth, it is, as we ſaid before, ſwallowed down into the Stomach, after it is well mixed with the Spittle, which by the Motion of its Parts while it continues a Liquid, ſerves like *Aqua-Fortis* to diſſolve it further than the Teeth could do. And this is confirmed from hence, that the Food is much eaſier to concoct, if it be well chewed and mixed with a good deal of Spittle, than if it be leſs chewed and ſwallowed down into the Stomach almoſt dry.

5. That the Spittle helps Concoction.

6. But this is not at all. For there are a great many Branches of Arteries, the Extremities of which are in the Inſide of the Stomach; from ſome of which there generally diſtils another Sort of *Aqua-Fortis* much ſtronger than the other, which mixing with the Spittle, helps it to diſſolve the Victuals, and indeed does the moſt towards it.

6. Of another Liquor that gets into the Stomach.

To which we may add further, that we may not wholly diſagree with the Antients, that theſe two Sorts of Liquors, in Man and in the greateſt Part of Animals, require Heat in the Stomach, in order to diſſolve the Victuals contained in it.

7. That the Gall finiſhes the Concoction of the Victuals.

7. The Victuals after being thus diſſolved, go into the Inteſtines, where it may be ſaid, that a ſecond or a third Concoction is made: For the Gall which continually diſtills into them, and which tinctures the Victuals almoſt as ſoon as they come out of the Stomach, finiſhes, as the laſt Diſſolvent, what the preceeding ones only began.

8. That the Gall is not a meer Excrement.

8. If what I have ſaid concerning the Gall does not agree with the Opinion of ſome Phyſicians, who think that the Gall is nothing but an Excrement and of no uſe in the Body, I ſhall not be very uneaſy at that; becauſe their Opinion is ſo far from being ſupported by Reaſon, that it is directly contradicted by it. And indeed, if the Gall were only a meer Excrement, it is very probable, that Nature would rather have placed it at the further End than at the Beginning of the Inteſtines: For if their Opinion be true, it ſerves only to taint the Victuals as ſoon as it comes out of the Stomach, before it has furniſhed what is neceſſary to nouriſh the Body.

CHAP. XXI.

Of the Motion of the Chyle.

1. What the Chyle is.

IN what Manner ſoever the Victuals are prepared, when they enter into the Inteſtines, it is very certain, that that Part which is ſeparated from them in order to be converted into Blood, muſt be very fluid, becauſe the Paſſages it goes through are ſo ſmall as not to be diſcovered by the Eye. This Liquor is what we call the *Chyle* which is ſeparated (whatever the Cauſe of that Separation be) from the other Matter which is more groſs, and muſt go ſome Way to that Part of the Body where it is to be converted into Blood.

2. The Notion of the Ancients a-

2. The Ancients, who made Enquiry after theſe two Things, imagined that the Chyle was drawn out of the

Inteſtines by the Extremities of the Branches of the *Vena-Porta*, to which they aſcribed a Power of ſucking. That after this, the Chyle continued to run towards the Liver, by which it is likewiſe attracted, and into the Subſtance of which it enters, and that at laſt the Liver converts it into Blood.

bout the Motion of the Chyle.

3. Though this Opinion was received in the Schools for a long time, yet were they forced to reject it at laſt; becauſe no Body underſtood what that Vertue of ſucking was which they aſcribed to the meſentery Veins; nor what that Vertue of attracting the Chyle and converting it into Blood, conſiſted in, which they aſcribed to the Liver; but chiefly becauſe, according to that Opinion, the Chyle muſt run from the Inteſtines to the Liver, through thoſe Veins which they affirm, carry the Blood at the ſame Time with a contrary Motion from the Liver to the Inteſtines, which without Doubt is contrary to common Senſe and Reaſon.

3. That this Opinion is contrary to Reaſon.

4. Indeed ſince it has been found out, that the Blood circulates and runs out of the Branches of the cœliack Artery into the Veins of the Meſentery, and ſo is carried from the Inteſtines to the Liver; it is rightly judged, that the Blood is ſo far from hindring the Motion of the Chyle, that it cannot but contribute to make it move the eaſier.

4. That this is become probable, ſince the Circulation of the Blood was known.

5. But though the great Difficulty which was found in the Opinion of the Ancients, was hereby removed; yet the Diſcovery which was ſometime ſince made of the *lacteal Veins*, in which the Chyle appears viſibly to be contained, has cauſed it to be entirely rejected; And except ſome few of our old Phyſicians, who can't bear to alter their Opinions, there is none at this Day but hold, that the Chyle does not enter into the meſentery Veins at all, but only into the lacteal Veins.

5. That the Diſcovery of the lacteal Veins has cauſed it to be entirely rejected.

6. And there being yet no Doubt concerning the Place where the Blood is made; they ſtreight concluded that the lacteal Veins did ſerve as Channels to carry the Chyle directly from the Inteſtines to the Liver.

6. The firſt Opinion concerning the Courſe of the Chyle.

7. However they were forced to reject this Opinion alſo, upon finding by Experience; that when the Liver of a live Animal is cut out of the Body, the lacteal Veins do not empty themſelves at all. For it is certain, that if the Chyle went directly to the Liver, thoſe Veins ought to grow empty, becauſe all the Paſſages through which it goes would be open.

7. That the Chyle does not go to the Liver at all.

8. During

8. of the Course of the Chyle.

8. During this Uncertainty of the Course which the Chyle did take; Mr. *Pecquet* thought of a Method of putting this Matter past all Dispute. It is an Experiment which he has made and shown a great many Times, and whch discovers the Course of the Chyle so as it may be seen with the Eye. The two subclaviary Veins must be tied a little above the Place where they discharge themselves into the *Vena-cava*; that there may be no Communication betwixt that Part which is above the Ligatures, and that Part which is below them; then having opened the right Cavity of the Heart, all the Blood which is beneath the Ligatures must be let out and carefully wiped up with a Sponge; after which, having first squeezed the lacteal Veins, then the Receptacle of the Chyle, and last of all the Duct which goes along the Vertebræ, these Vessels will grow empty one after another, and you will see all the Chyle go into the right Cavity of the Heart. And this made us think, though we expected another Passage, that all the Chyle passes from the Intestines into the lacteal Veins; and from these Veins into the Receptacle, and from thence into the subclaviary Veins, where it mixes with the Blood, and goes directly to the Heart.

9. That the lacteal Veins, do not attract the Chyle.

9. Nor is it at all necessary, in Order to explain how *the Chyle comes out of the Intestines*, to ascribe a Power of sucking to the lacteal Veins as the Ancients did to the mesentery Veins. It is sufficient to imagine, what is agreeable to Reason and Experience; that every Thing which is in the Intestines is in a continual Fermentation or Agitation, which makes all the Parts to have a Tendency to dilate themselves every Way. For, upon this Supposition, it is easy to apprehend, that the finest Parts, which are the most proper to make Chyle, get through the Pores of the Intestines and so enter into the lacteal Veins.

10. That the Chyle moves the same in Men as in Beasts.

10. The Course of the Chyle was for a long Time shown by Experiments in Beasts only, which gives Occasion to them who are still of the Opinion of the Ancients, to contend, that it does not move in the same Manner in Men. However this Matter is now put past all Dispute by an Accident that has happened. Two drunken Soldiers having quarrelled and fought together, and one of them being very much wounded, was carried to a Surgeon, but was just dead when he got thither. This Surgeon (Mr. *Gaian*) who is very well skilled in Anatomy, kept the Body, and sometime after having dissected it, he shew'd the Motion of the Chyle to be the same in Men

as

as in Beaſts. Several Perſons were ſucceſſively Witneſſes to the Experiment; And when the Chyle would not laſt any longer, he ſupplied the Want of it, by putting the End of a ſmall Syringe into the Receptacle and injecting ſome Milk; for by that Means they ſaw it diſcharge it ſelf into the right Cavity of the Heart, the ſame as the Chyle did. If this Experiment be not ſufficient to ſhew the Courſe of the Chyle in the Body, I know of no Means that there can be of demonſtrating it.

CHAP. XXII.

How the Blood is made.

IF what has been ſaid concerning the Courſe of the Chyle be granted, the Opinion of the Ancients, that the Blood is made in the Liver, appears manifeſtly falſe: And there will be no Room to doubt but that the Chyle is converted into Blood in the Heart.

1. That the Blood is made in the Heart.

2. As to the Manner in which the Chyle is converted into Blood, I ſhall not ſay of the Heart what is uſually ſaid of the Liver, *viz.* that, being itſelf red, it communicates its Redneſs to the Chyle: For this is not at all neceſſary; for we very well know, that a Chicken, which has Blood in its Arteries and Veins, is generated from an Egg, the Shell of which is white, the White of the Egg tranſparent, and in which there is no Red at all. I think therefore, that it is more probable, that the Chyle becomes red by the Alteration which the Ebullition it acquires in the Heart makes in the Figure and Diſpoſition of its Parts. So that the Heart contributes no more to the making of the Blood then a Kneading-Trough does to the making of Paſte.

2. How the Blood is made.

3. According to the different Conſtitutions of Men, the Chyle is converted into Blood ſooner in ſome Perſons than in others. And there are ſome, who have no ſooner eaten, but we may perceive by very viſible Effects, that Part of the Food is concocted, and the Juice got into the Heart; For that Diſpoſition to ſleep which they have immediately after eating, cannot reaſonably be aſcribed to any Thing elſe but the Want of animal Spirits, which do not then breed in ſo great Plenty in the Heart, becauſe the

3. When the Blood is made, and why ſome People after eating are very ſleepy.

the Blood which passes through it at that Time is become too gross and cool by the Chyles mixing with it.

CHAP. XXIII.

Of the EXCREMENTS.

1. Of the different Sorts of Excrements.

SINCE we are assured that all the Parts of the Food that we take are not converted into Chyle, but that a great Deal of it becomes an useless *Excrement*; it is very reasonable to think also, that all the Chyle is not converted into Blood, nor all the Blood applied to the Nourishment of our Bodies: So that there are several Sorts of *Excrements*, and of a very different Nature, which are also separated in several different Manners from the Body; And indeed we may affirm, that there is no Part of the Body but what will become at last an *Excrement*; because there is no Part which at some Time or other will not be separated from the Body, seeing it is in perpetual Change, and subsists by such Change.

2. The Opinion of the Ancients concerning the Separation of the Urine and Sweat.

2. The Parts of the Food which are not converted into Chyle, being grosser and not so fluid as the Chyle, cannot pass along with it into the lacteal Veins, but are discharged by an Intestine appointed for that Purpose. But it is not thus with the Chyle in Respect to the Blood: for both these being equally fluid, we may very well imagine, that all the Parts of the Chyle which are not converted into Blood, and which consequently are a Kind of Excrement, follow it every where, so that they go together all the Way. And this is the Reason why the Ancients, who believed that the Blood was made in the Liver, affirmed; that at the making of the Blood the Excrements of it were carried from the Liver through all the Veins; but that some Part of them was attracted by the Kidneys in Order to make *Urine*; and the other Part went off in *Sweat* through all the Parts of the Body indifferently.

3. That this Opinion was confirmed by finding out the Circulation of the Blood.

3. This Opinion appeared very plausible, both because the Blood which is let out of the Veins, if it be left to settle a little, is found to be full of a certain Serum which very much resembles Urine; and also because the Kidneys are

are placed juſt by the Extremities of the emulgent Veins and Arteries, through which we conceive the Parts of the Urine are able to paſs. And though ſome Perſons rejected this Opinion at firſt, and ſeemed confounded at it, becauſe it ſuppoſed an unintelligible Attraction, the Sphere of whoſe Activity reached from the Kidneys to the extreme Parts of the Body; yet this Difficulty ſeem'd to be taken off by the Diſcovery of the Circulation of the Blood. For they imagined that as the Blood paſſed continually out of the Artery into the emulgent Vein, the Parts of the *Urine* which are mixed with it there, might diſcharge themſelves through ſuch Pores as would carry them to the Kidneys. Nor was there any further Need of aſcribing any attractive Vertue to the Kidneys, becauſe the *Urine* may get thither in the ſame Manner, as the Meal does through the Holes of a Sieve into the Baker's Trough, though there be no attractive Vertue in it. And thus this Opinion had all the Appearance of Truth in it.

4. That it is probable there is ſome Paſſage for the Urine which we do not yet know.

4. But ſince Philoſophy began to be improved with greater Diligence than formerly, and Nature has been more exactly enquired into; though it is believed that the Urine does go that Way which we juſt now mentioned, yet they begin to ſuſpect that there is another Way beſides, through which it gets into the Kidneys and then into the Bladder. The Reaſons for this ſeem to be very ſtrong. For *Firſt*, we find that if a Perſon be let Blood immediately after having eaten Garlick or Sparagraſs; neither the Blood nor the Serum will ſmell of it as the Urine does; which it ought to do if the Urine were only the Serum of the Blood. *Secondly*, It is very difficult to conceive how they who drink any large Quantity of Water, eſpecially any Mineral Water, ſhould have it get through them ſo ſoon, if it does not go into the Bladder ſome ſhorter way than that which I have mentioned. I forbear taking Notice of what Alteration and Change it muſt make in the Motion of the Heart, and Temperature of the whole Body, by paſſing through the Heart in ſo large a Quantity as it muſt do. And further yet, it has not been hitherto obſerved that the Serum of the Blood is always tranſparent, and exactly of the ſame Colour with the Urine. All theſe Reaſons have cauſed the Phyſicians to begin to ſuſpect, and to propoſe the following Queſtion to be debated, *viz.* Whether the *Urine* be not an Excrement of the firſt Concoction, that is, ſuch as ariſes from the Preparation of the Chyle only, and not from the

the Converſion of the Chyle into Blood. As for my ſelf, I think this Suſpicion is very well grounded; and I am very much inclined to think, that there is ſome Paſſage, through which, Part of the Urine may paſs out of the Receptacle of the Chyle immediately into the Kidneys. But becauſe I have not yet met with any Experiment to confirm this Conjecture, I ſhall determine nothing further about it.

5. Through what Paſſages the Urine gets into the Bladder.

5. As to the Paſſages out of the Cavity of the Ureters into the Bladder, though they are not at all viſible, as was obſerved before, yet we are ſure that their Conſtruction is ſuch, as that they have ſmall Valves which will permit the Urine to go down into the *Bladder*, and not ſuffer it to return into the Ureters again. For if a Bladder be taken out of the Body of an Animal, and filled full of Water, there will not run a Drop of it out for a great many Days, that is, till it is decayed; whereas if the Inſide be turned outwards and then it be filled with Water, it will all run out in two or three Hours.

6. Of Sweat.

6. The Particles of Sweat diſcharge themſelves from the Blood, at the Time that it gets out of the Pores of the Arteries to cauſe Nutrition, and it flies quite off from the Body by the ſmall Spaces which are between the Fibres of the Fleſh.

7. What the Matter of it is.

7. It is highly probable that the Matter of *Sweat* is the ſame as that of *Urine*; for, beſides finding the ſame Sort of Salt in *Sweat* that we do in *Urine*; we alſo ſee that the more *Sweat* there is, the leſs is the *Urine*.

CHAP. XXIV.

Of Hunger and Thirſt.

1. How Hunger is raiſed in us.

Hunger and *Thirſt* are two Senſations or two natural Appetites which are excited in the Soul from Time to Time by the Action of the Nerves of the Stomach and Throat. And in order to ſee how this is done, we muſt obſerve, that when the Stomach is empty, that is, not filled with Victuals to cauſe Nouriſhment; then the Liquor which conſtantly deſcends from the Arteries into the Stomach,

Stomach, and which commonly ſerves to digeſt the Victuals which are there, finding nothing for them to act upon, agitate and ſhake the Nerves of the Stomach; which Motion being carried to the Brain, excites in the Soul, the Senſation or Appetite of *Hunger*.

2. And if the Humour which conſtantly aſcends from the Stomach to the Throat, in the Form of a moiſt and groſs Vapour, in Order to keep the Parts as moiſt as is proper for the Good of the Body, be too much heated and in too great Agitation; either becauſe it is not tempered with ſome other Liquor, or becauſe the Heat which is all over the Body increaſes the Agitation of it, or any other Cauſe whatſoever; ſo that it aſcends in the Form of Air or of ſome very fine Vapour; then inſtead of moiſtening and cooling the Throat, it will heat and dry it; and this will cauſe a Motion in the Nerves, proper to excite in us the Senſation of Thirſt.

2. How Thirſt is raiſed in us.

CHAP. XXV.

Of Sickneſs and Health.

HEALTH is a particular Diſpoſition of the Body whereby it is enabled readily to perform all the Duties belonging to it.

1. What Health is

2. Two Things generally go to this Diſpoſition; namely, *a fit Conſtruction of the Parts*, and a *juſt Temperature of them*. Which two Things come pretty near to one and the ſame. For by the Word *Temperature* we mean a particular Mixture and Combination of Qualities; and by all that has been ſaid in ſeveral Places in this Treatiſe, it is evident, that what we call a *Quality*, is nothing elſe but a particular Diſpoſition and Texture of *ſmall imperceptible Parts*, which compoſe the *larger viſible Parts* of the Body.

2. What it conſiſts in.

3. *Sickneſs*, on the contrary, is a particular Diſpoſition of the Parts of the Body, which renders them incapable of duly performing their reſpective Functions.

3. What Sickneſs is.

4. Though Sickneſs attacks the whole Man, yet it conſiſts chiefly in the Body; and the Pains which it cauſes in the *Mind* are only Conſequences of it, as appears from hence, that by uſing Remedies which affect only the Body,

4. That Sickneſs is in the Body only.

and reduces it to its former State, all the Pains and Uneasiness, which the Mind feels, immediately cease.

5. Of Distempers arising from the bad Construction of the Parts.

5. There are generally reckoned two Sorts of Distempers, the one consists in *a bad Construction of the Parts*, as when they are too large or too small, or not of the Shape that they ought to be.

6. Of Distempers arising from ill Temperature.

6. The other consists in an *ill Temperature*; that is, in a *particular Mixture of the Qualities of the Body* which is not such as it ought to be. And we call it a *manifest ill Temperature* if we know the Qualities which are in Disorder; but we call it *occult*, when the Qualities and the Cause are unknown.

7. Of the Cause of Distempers.

7. All Distempers are generally owing to the ill Regulation of our Lives, either from too much or too little Sleep, too much or too little Exercise, *&c.* Sometimes they are caused by things without, and very often by the Abuse of Food; that is, by our Intemperance in eating and drinking; which is so much the more injurious to us, because it affects us inwardly.

8. What a Fever is.

8. My Design is not to treat of particular Distempers here: However there is an extraordinary kind of Burning in the Body, which Physicians call a *Fever*, which I cannot wholly pass by in Silence; and there is the more Reason to enquire about it, because this Distemper goes along with almost all others; and besides, its Intermissions are the most surprising to all Philosophers.

CHAP. XXVI.

Of a FEVER.

1. What a Fever consists in.

AFTER what has been already laid down concerning the Construction of a human Body, it will be easy to explain all the surprizing Phænomena or *Symptoms* of a *Fever*. For we need only to imagine, a small Part of our Blood or any of those Juices which are mixed with it as it runs towards the Heart, any Way to stagnate in some Part of the Body, so that it does not begin to move for some Time, till it be so corrupted, that it resembles green Wood when it begins to burn; that is, as such Wood, when it is first

first laid upon the Fire, seems not disposed to burn, but rather extinguishes the Fire; so likewise, this small Portion of corrupted Juice, has no Tendency to grow hot and dilate it self at first, when it passes through the Heart. And as green Wood burns afterwards brighter and more fiercely, than that which is dry, so also does this Juice at length grow hotter and dilates it self more, than the Blood ordinarily does.

2. Now this being supposed, we are sure in the first Place, that when this sluggish Humour begins to move from the Place in which it was corrupted (which I shall henceforth call the *Seat of the Fever*) and to mix with the Blood; it will hinder it from dilating itself as usual in passing through the Heart, and consequently the Heart and Pulse will then beat very faint.

2. Why the Pulse is weak when a Fever begins to approach.

3. And what ought particularly to be observed here is, that the vital Spirits moving much slower than usual in the Body, the Agitation of the Particles which is kept up by them, and in which the ordinary Heat of the Body consists, must be very much diminished. Whence it follows, that we must feel a certain Coldness, which is called the *cold Fit of a Fever*; which may be attended with some sharp or faint *Twitches*, according as the corrupted Matter, which runs in the Arteries agitates the inner Coats of them; or according as some of its Parts, which get through the Pores of the Arteries, differently move the Capillaments of the Nerves which they meet in their Passage.

3. Of the Shivering.

4. And because in this State it is impossible but that fewer Animal Spirits should be produced and those less agitated than usual; therefore those of them which are sent towards any Muscle, either to move the Body or to keep it in a particular Posture, are neither strong enough, nor sufficiently numerous to press against and stop up the Valves of the Pores so close, but that they are able to get out; in the same manner as when a little Air drawn into the Bellows gets out again, because it cannot press the Flap strong enough against the Hole; so the Spirits sent into the Muscles, get out, and go along with a trembling Motion from one Muscle to another, and so draw the Members by turns to the opposite Sides, and make them shake; that is, cause that *Trembling* which usually attends the Shivering or Coldness in a Fever.

4. The Cause of the Trembling.

5. And though all the corrupted Matter may perhaps have passed through the Heart in less than half an Hour,

5. Why the Shivering

continues sometimes for a great while. yet it may make the *Shivering* continue much longer; because this Matter which is mixed with the Blood may return to the Heart again, with as little Disposition to dilate it self as it had the first Time it passed through it.

6. How the Matter of the Fever may come to burn. 6. As green Wood after it is once heated, burns fiercer than dry Wood; so the corrupted Matter, after it has passed several Times through the Heart, may at last acquire such a Disposition, as to be very much rarified, and to come out of the Heart very much quicker and more agitated than the Blood usually does; and this is sufficient to produce all those Effects, which we experience in that State called the *hot Fit of the Fever*, which succeeds the great Coldness.

7. Of the Quickness of the Pulse and the vehement Heat of the Fever. 7. And, *first*, as to the Beating of the Pulse, it is evident, that it must be quicker and higher than usual, because the Blood flows quicker into the Arteries, and with greater Force and Agitation than it commonly does. We ought also to perceive a very extraordinary Heat, because the Blood which comes boiling, as it were, out of the Heart, is carried very swiftly to the extreme Parts of the Body, without having any Time to cool it self by the Length of the Way.

8. The Difficulty of sleeping, the Pains of the Head and Members. 8. Further, because in this State, a very large Quantity of animal Spirits gets into the Brain, and from thence into the Nerves; there must necessarily arise a *Difficulty in sleeping, Pains in the Head*, and *that very troublesome Tenderness which we have in all the Members of the Body.*

9. Of a Delirium. 9. It may also happen, that the animal Spirits, which run irregularly in the Brain without any certain Determination, and which are very strong at that Time, may of themselves force open and agitate some Parts of it, in the same Manner as they are at other Times by external Objects; wherefore we ought then to see such Objects as if they were really present; and herein consist those strong *Deliria* which sometimes affect sick Persons so much.

10. Why a Fever wastes the Body so much. 10. And if the Distemper continues long; then because the Parts of the Blood which used to turn to Nourishment are in much greater Motion than ordinary, or than is necessary for them to be employed usefully; they may not stop in such Places where they are wanted, and where they might be applied to Nourishment; but pass off in the Form of Sweat or insensible Perspiration: And thus the Body may grow lean, in the same Manner as Plants wither in a very hot Summer, because the Juices which ought to nourish them, pass through their Pores without stopping.

11. And

11. And there will be no doubt but that a Fever is generated in the Manner I have been ſpeaking, if we conſider, that when there is any Pus made in an Abſceſs, or occaſioned by any Wound, in a Body otherwiſe in Health, a Fever generally enſues; and when this Pus ceaſes or makes it Way out of the Body, the Fever as generally goes off with it.

11. A Confirmation of the Truth of this.

12. Laſtly, though the Matter which kindles the Fever, may ceaſe any more to flow from its Seat or Receptacle, and though there be no new Matter mixed with the Blood that goes to the Heart; yet that which is already mixed with it, may be ſufficient to make the Fever increaſe, till after a great many Circulations, it be diſſipated, and the Blood ſo purified, that it is reduced very near to that Temperature, which Phyſicians call *laudable*. In the ſame Manner as Wine becomes fine at laſt, by working in the Veſſel.

12. How long it is before a Fever is at the Heighth.

13. When the Fever once comes to decline thus; it ought not to return again. Notwithſtanding there may remain a kind of Ferment, or certain evil Diſpoſitions, in that Place where the Blood is firſt corrupted; which may again vitiate and corrupt the Blood which gets thither, till by Degrees it come to Maturity, and running into the Heart as the firſt did, cauſe the ſame Symptoms.

13. How it may return.

14. Whence we may conclude that the Diſtemper will be a *quartan* Fever, if the Portion of Blood which ſtagnates will take up three Days before it comes to Maturity and be capable of running into the Heart along with the reſt of the Blood. If it takes up but two Days, it will be a *tertian* Fever; and if it continually runs, then it will be a *continued* Fever: And *laſtly*, it is a *continued* Fever *with Increaſe*, when the corrupted Matter has ſo vitiated the Blood, that it has not Time, betwixt the laſt Drop of the preceeding corrupted Matter coming out of the Heart, and the firſt Drop of new Matter collected again, running into it, to purify it ſelf; For then, there is an Opportunity for the corrupted Matter, which is very much diſpoſed to inflame, to go in great Quantity to the Heart, and ſo conſequently to cauſe a more violent Heat.

14. Of the different Sorts of Fevers.

15. And this is confirmed from hence; that this Matter which we have compared to green Wood, muſt firſt cool the Blood a little, before it ſelf can be rarified and heated beyond what the Blood uſually is; And thus, the firſt Time that it paſſes through the Heart, it cauſes ſome little Shiverings, and ſome Diſpoſitions to ſleep, ſuch as

15. A remarkable Circumſtance of a Fever with increaſe.

Yawnings and Drowſineſs, which precede the *Increaſe* of the Fever.

It is impoſſible to exhauſt this whole Subject. The humane Body is ſo wonderfully framed; that the leaſt Part of it will take up a Man's whole Life to underſtand it thoroughly: But becauſe it is very dangerous to be miſtaken in ſo important a Matter, upon which one's Life many Times depends, and to reaſon and argue upon falſe Principles, (as we ſee is perpetually done every Day;) and becauſe, we have but juſt begun to undeceive ourſelves in an infinite Number of Things, which we blindly received from the Ancients as true; we muſt wait, till we can get more Knowledge, from the Experiments which ſo many learned Gentlemen of the famous Academy are continually making with ſo good Succeſs: That by following the Light and purſuing the Diſcoveries of theſe great Genius's and firſt Maſters of Science, we may with more Aſſurance ſpeak concerning ſo nice and important a Subject; of which what we do already know, as little as it is, plainly ſhows us, that whole Schools have been deceived for many Ages, in eſtabliſhing their Maxims and Decrees, the very Foundation of which is falſe. Wherefore, when theſe Gentlemen ſhall be pleaſed to communicate to the Publick, what they have by their Labour and Care diſcovered; I hope they will permit me to make Uſe of their Diſcoveries, and to look upon them as belonging to me, in the Uſe and Application which I expect one Day to make of them; not by cenſuring what they intended for Inſtruction, but that I may correct my ſelf, if it does not appear to agree with the Principles which I have laid down, or elſe that I may be the more ſtrongly confirmed in the Truth of them.

FINIS.



AN

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Of the Principal

THINGS *and* PHÆNOMENA.

The First Number signifies the PART, the Second Number the CHAPTER, and the Third the ARTICLE.

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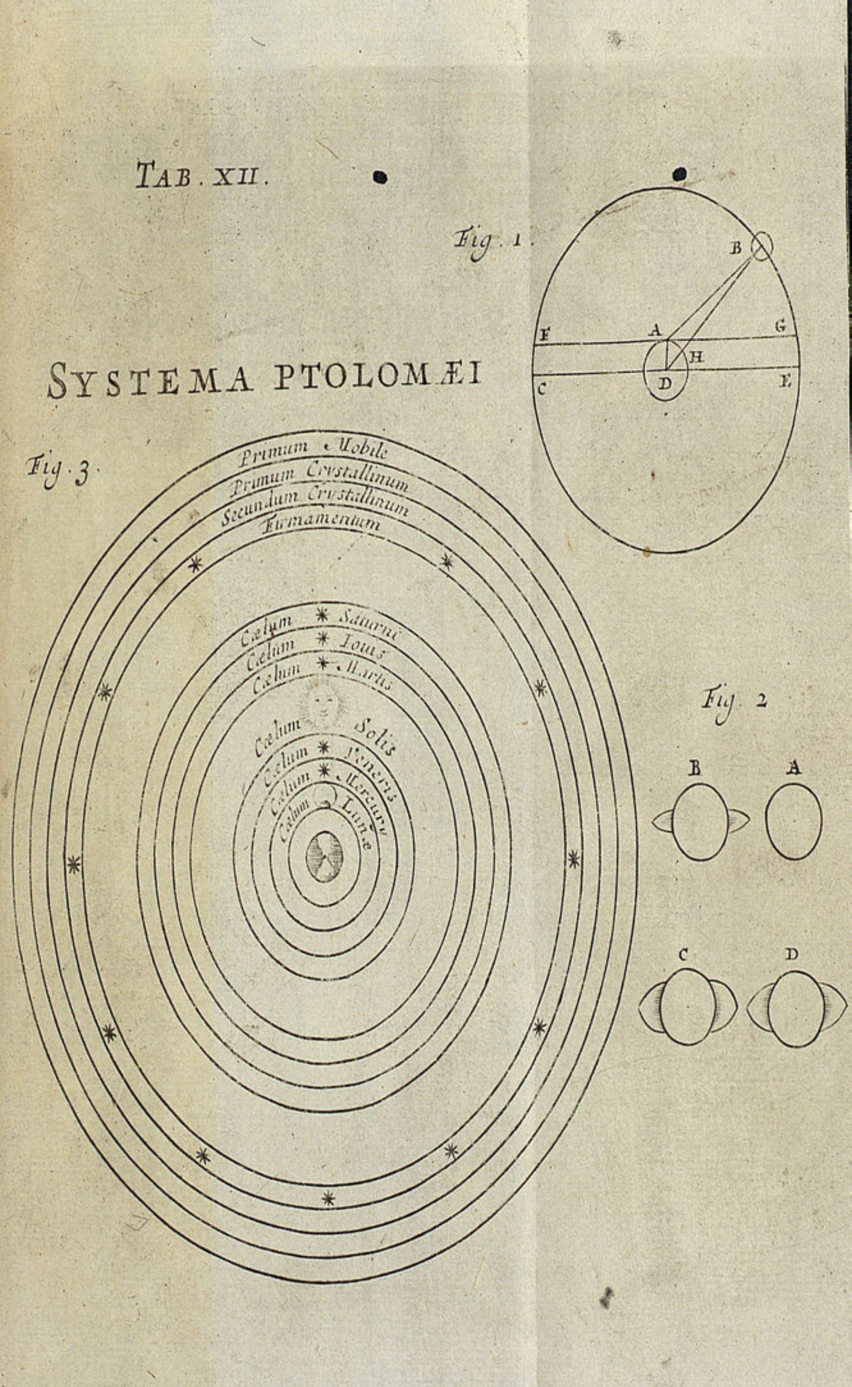
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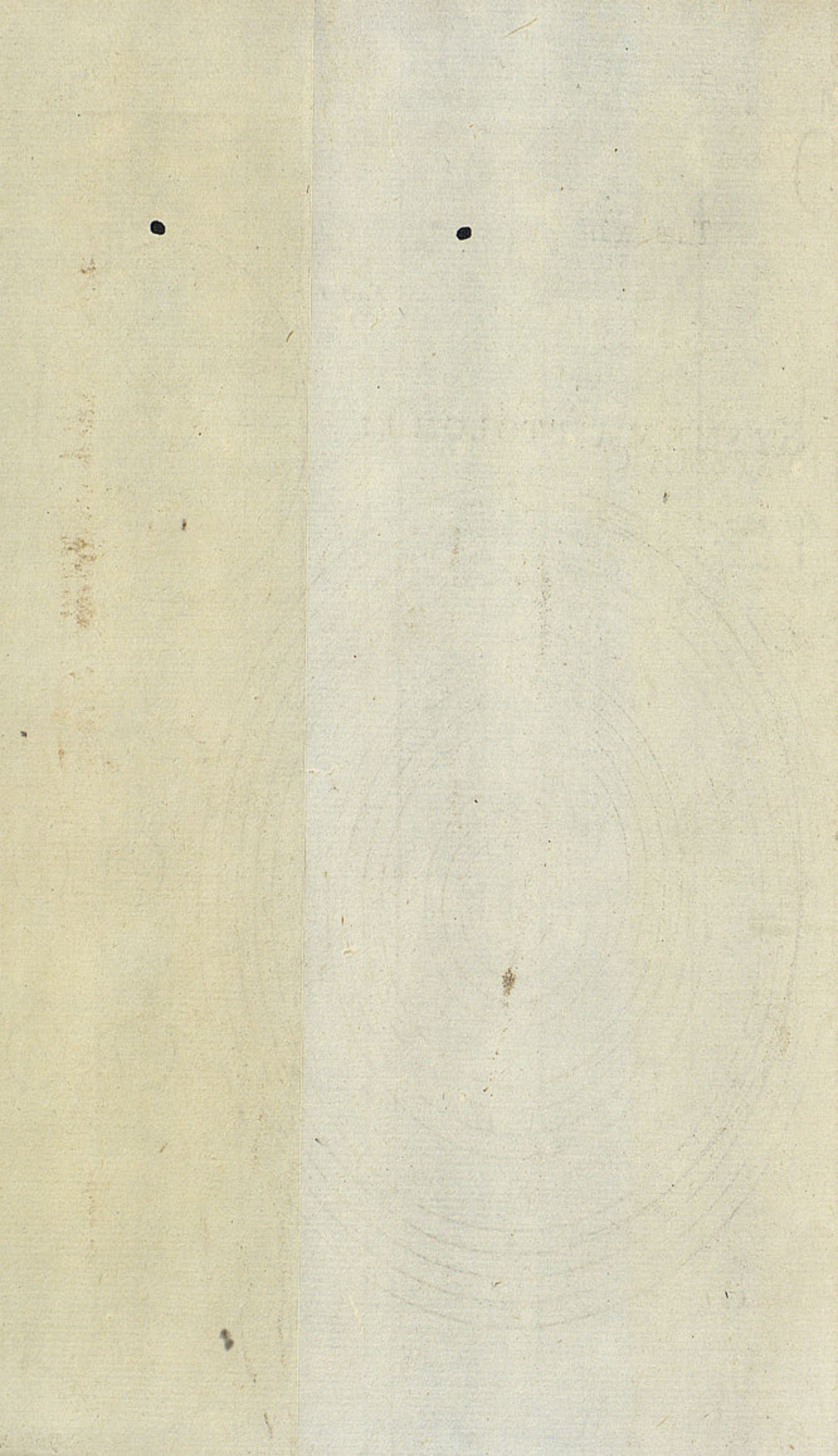
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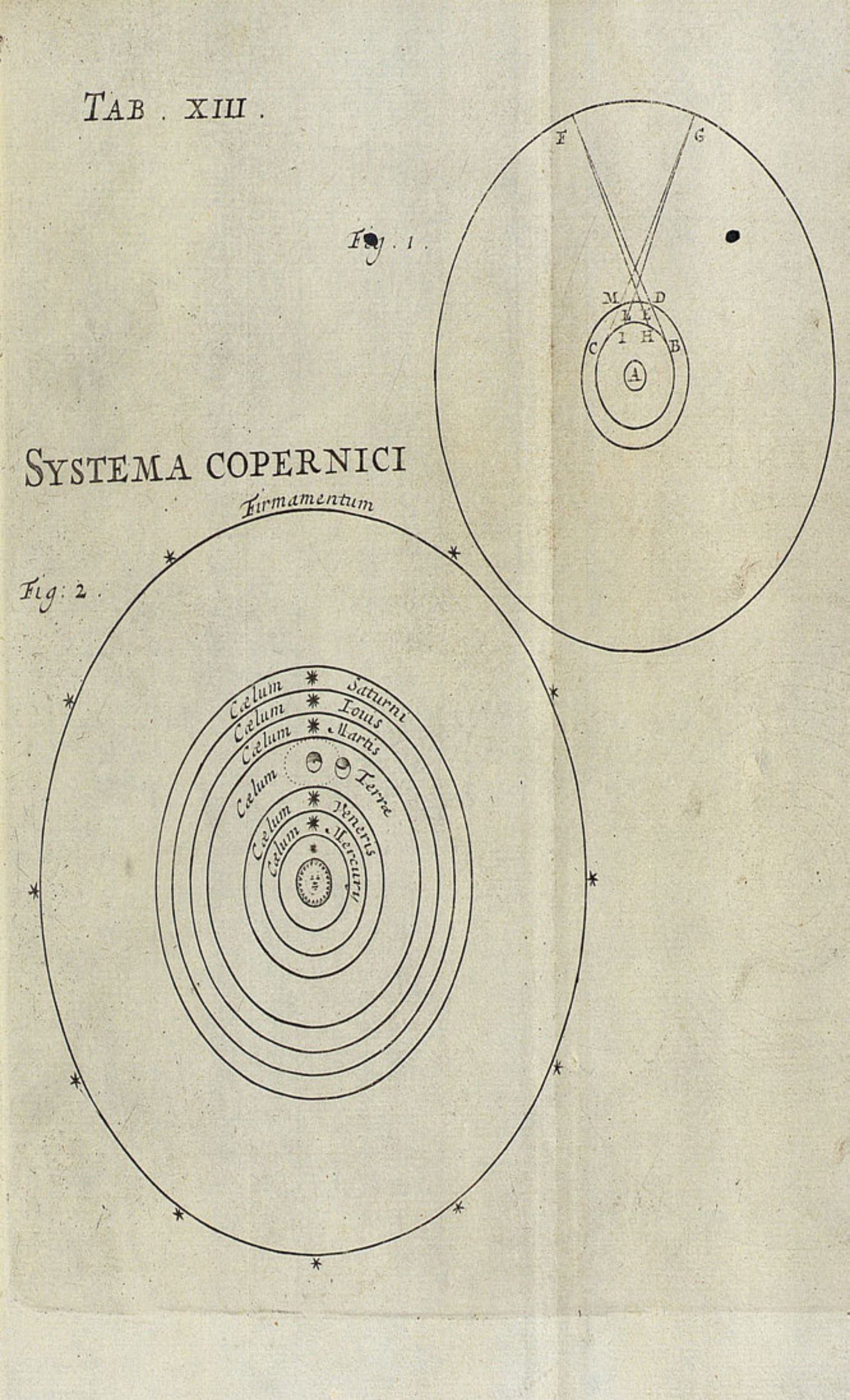
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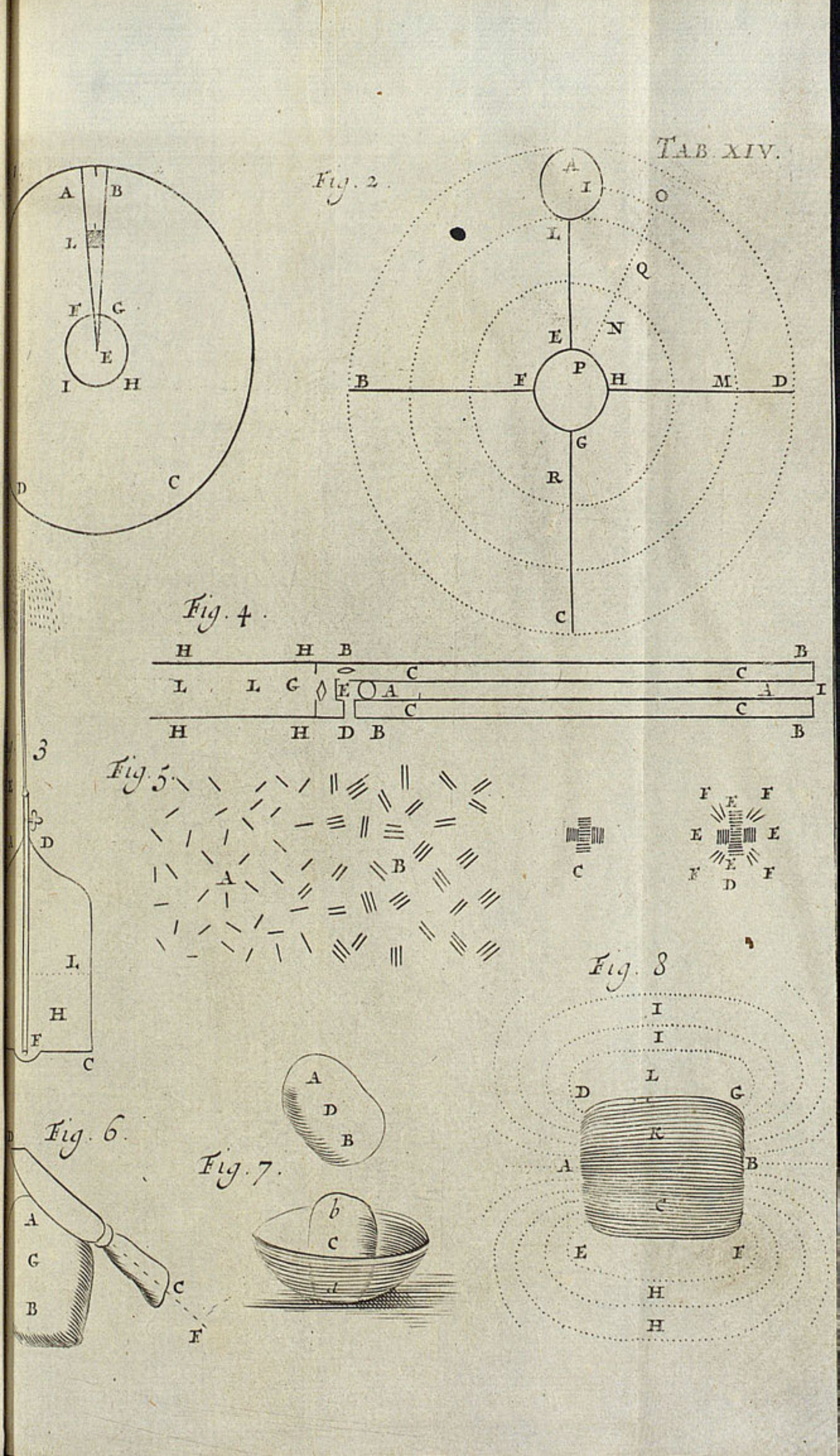
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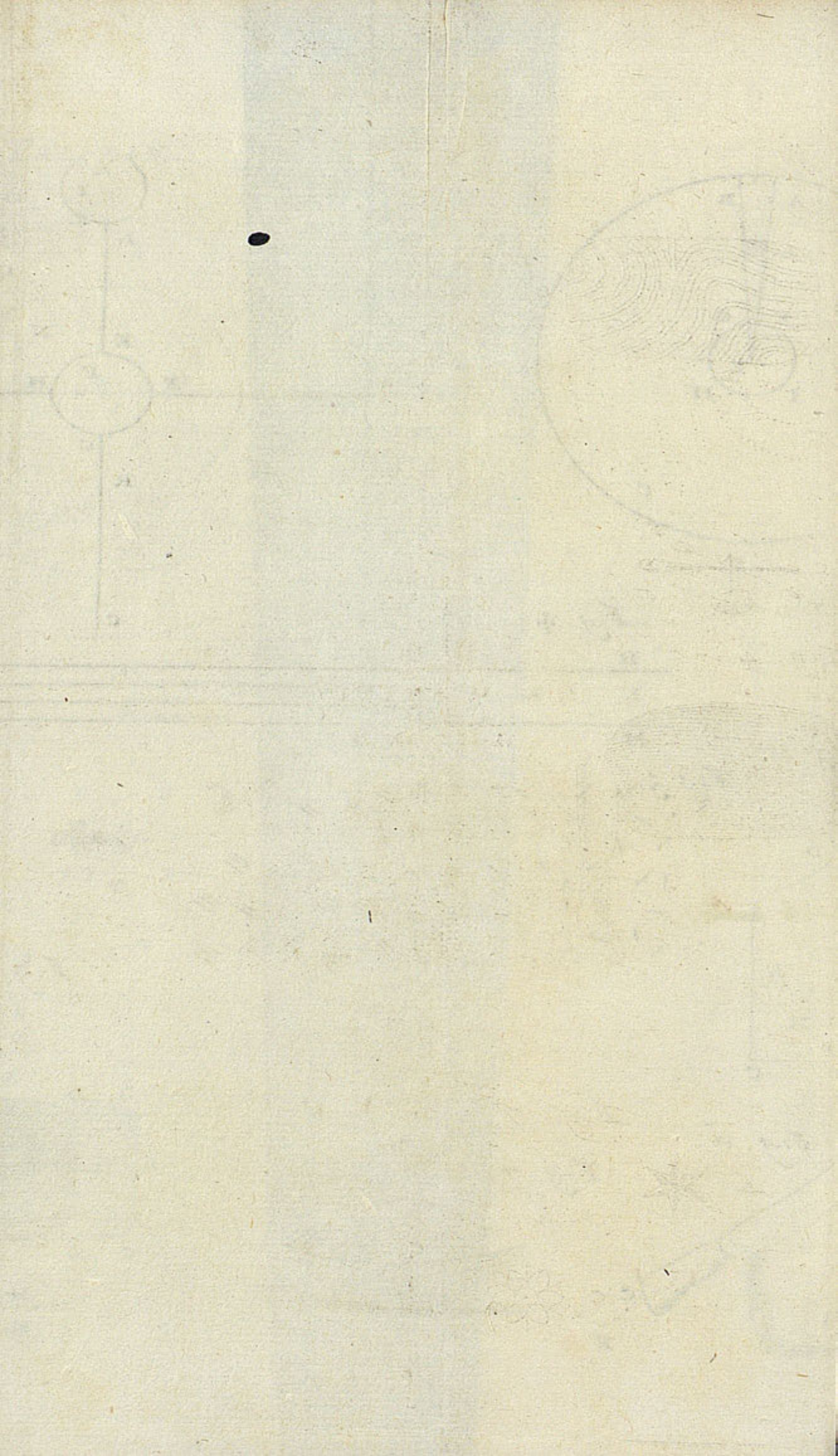

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Cælum Saturni
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Cælum Martis
Cælum Solis
Cælum Veneris
Cælum Mercurii
Cælum Lunæ
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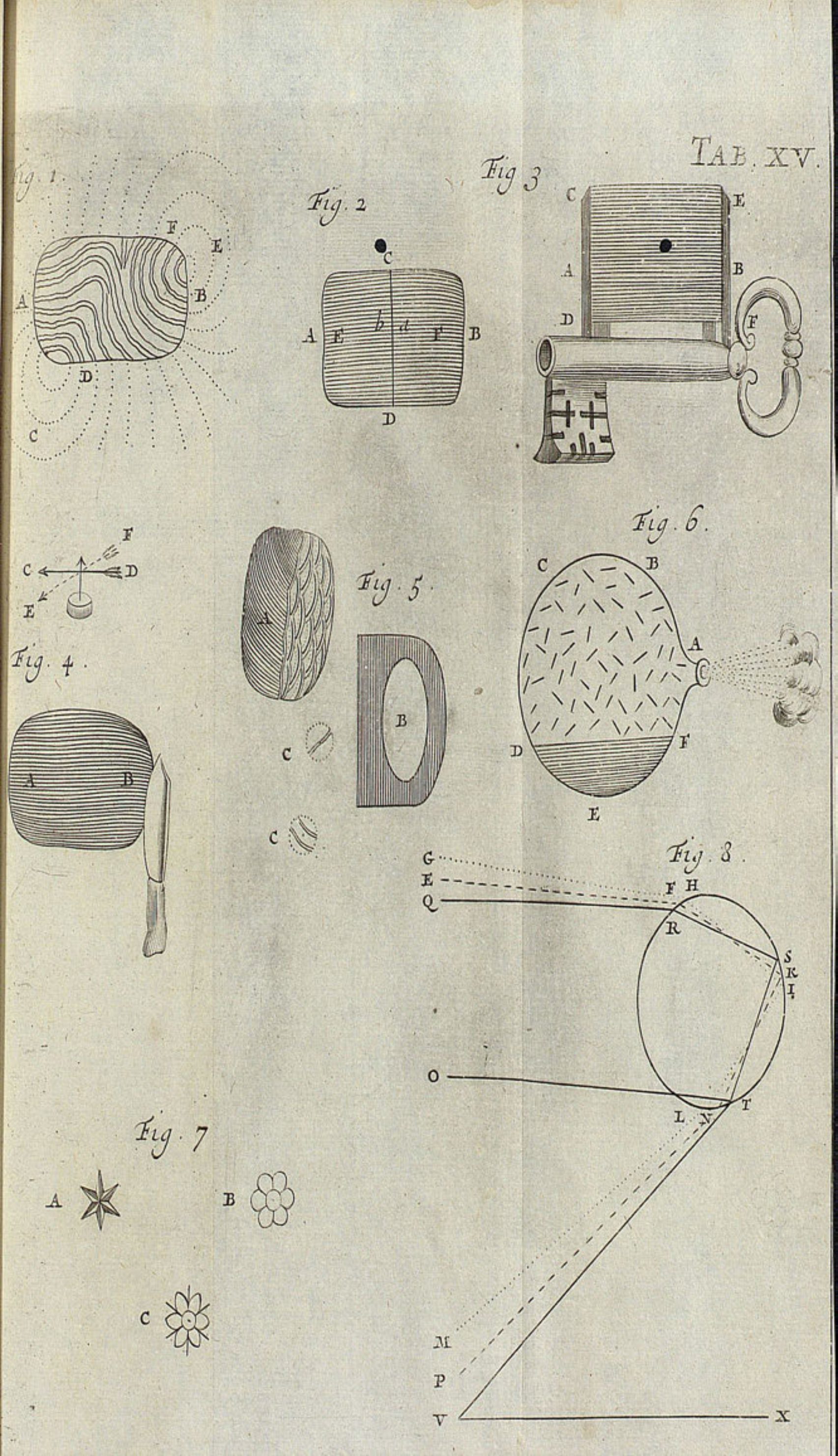


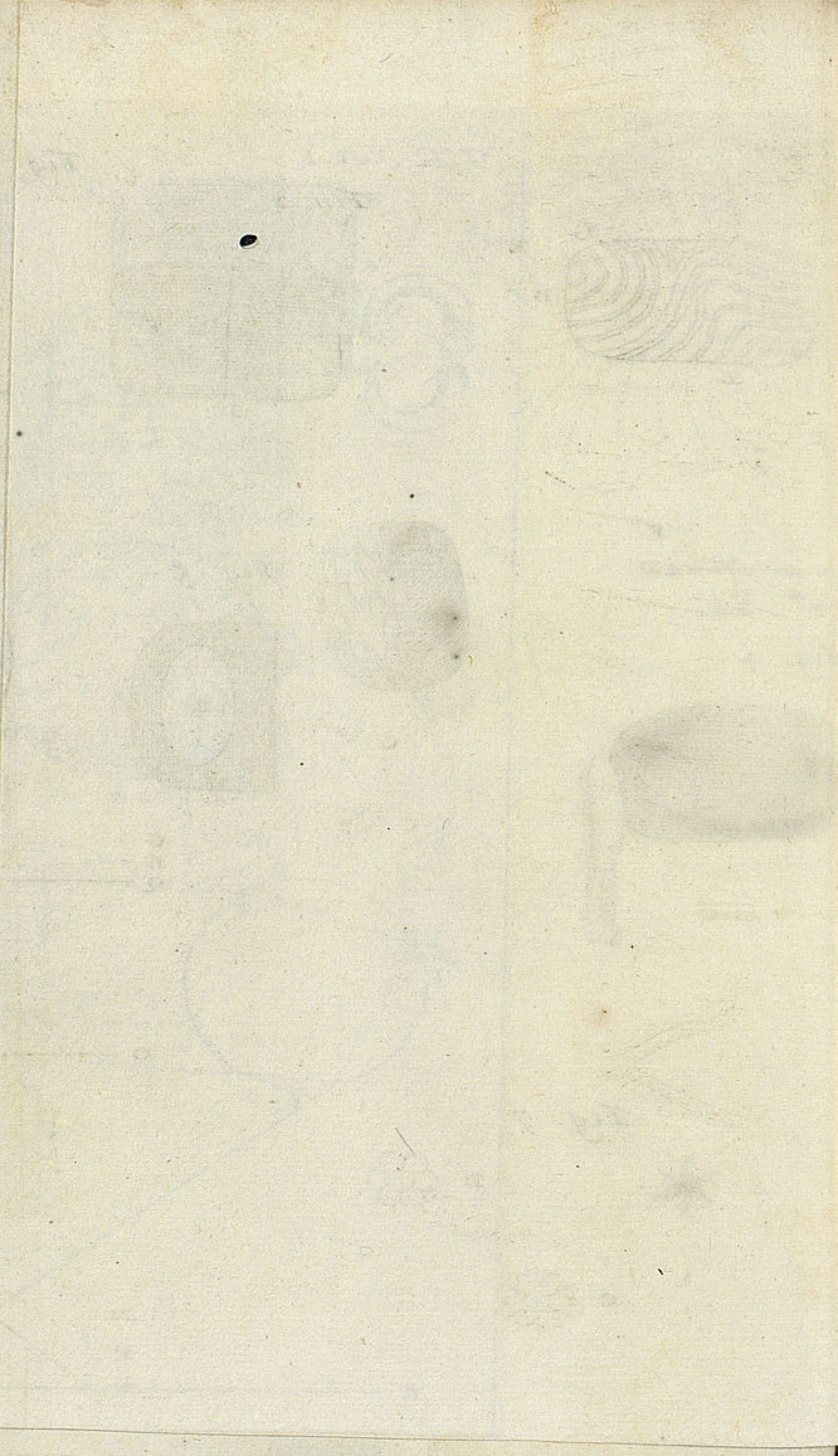


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Cælum Iouis
Cælum Martis
Cælum Terræ
Cælum Veneris
Cælum Mercurii

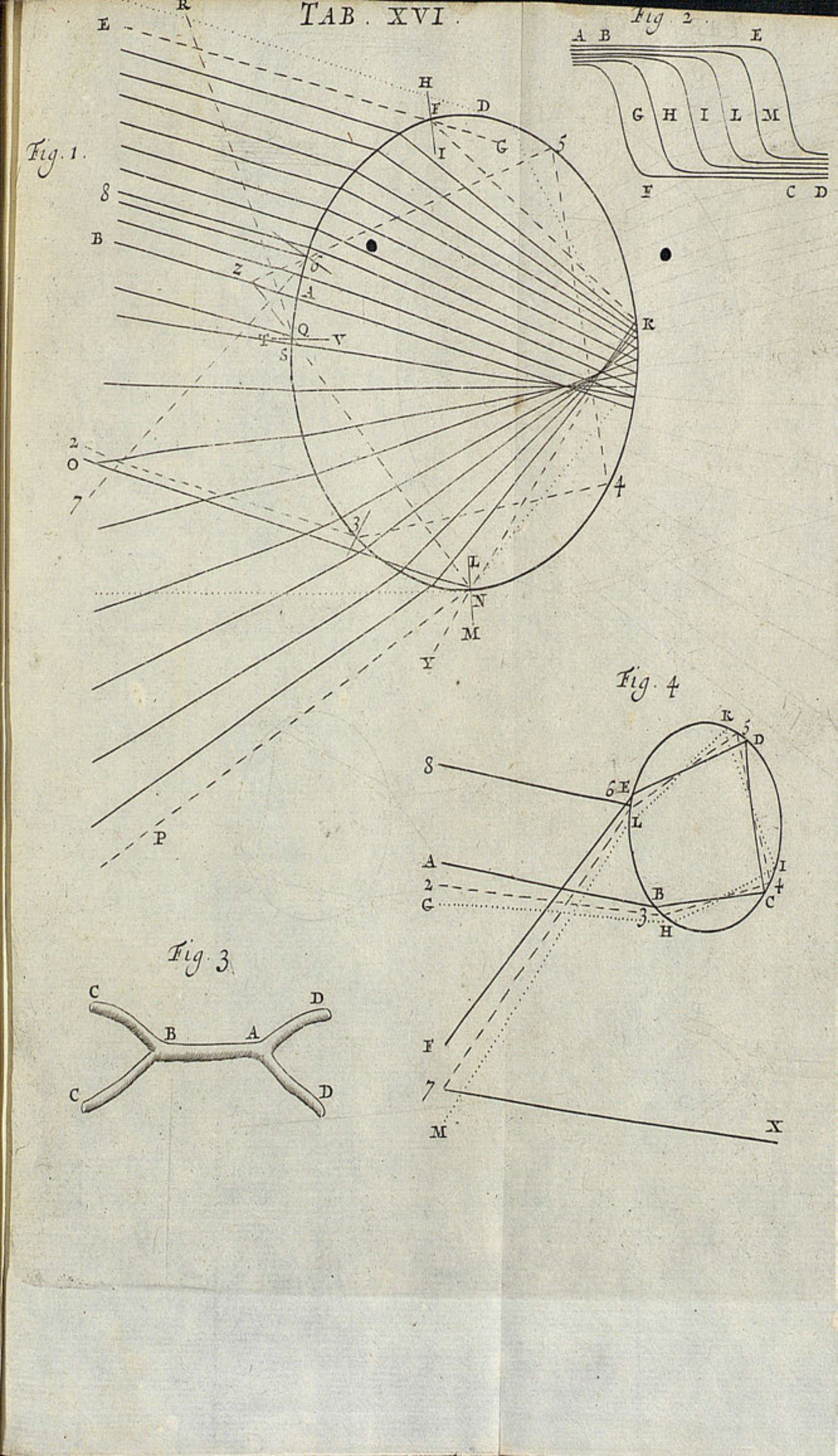

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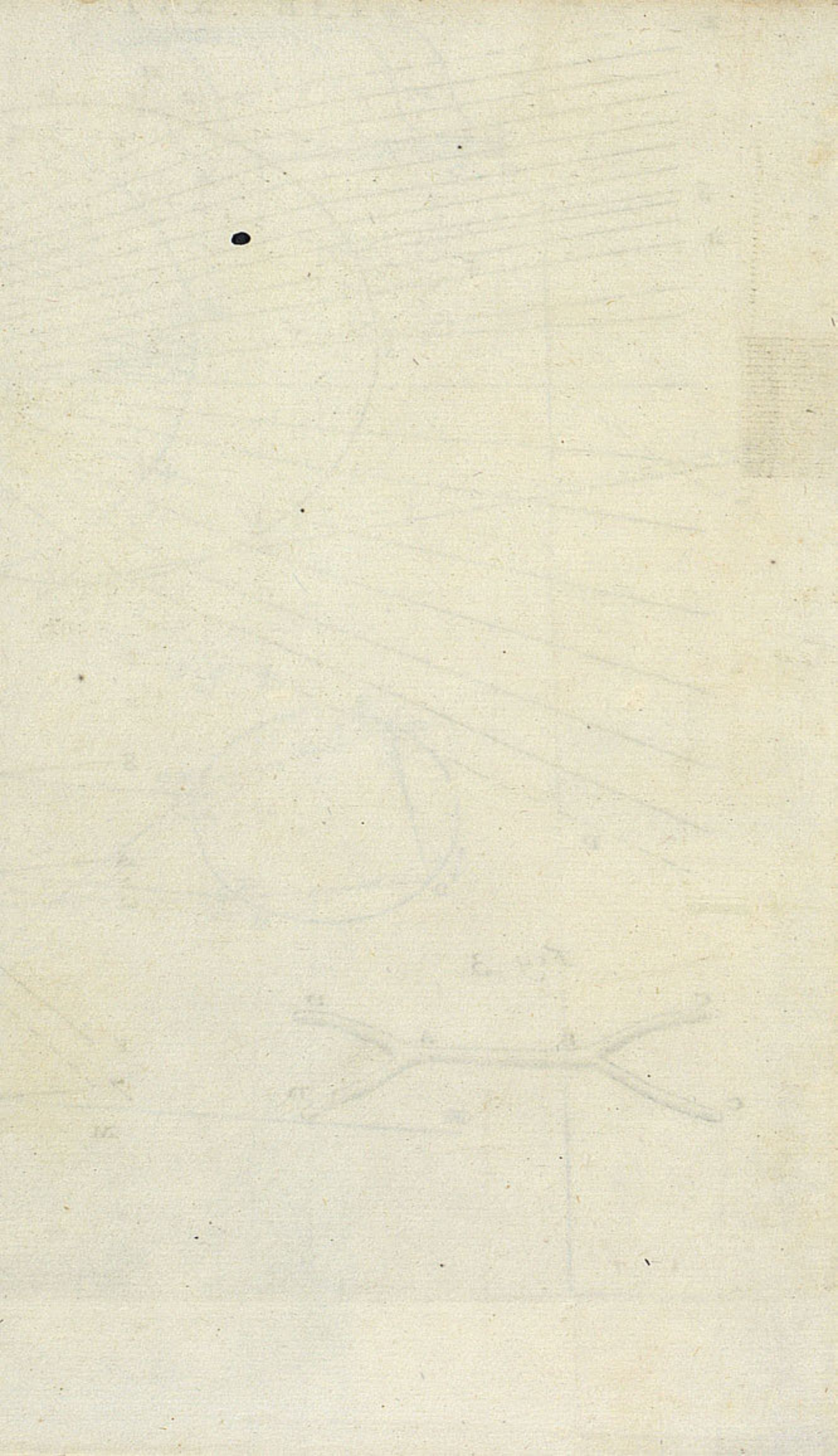


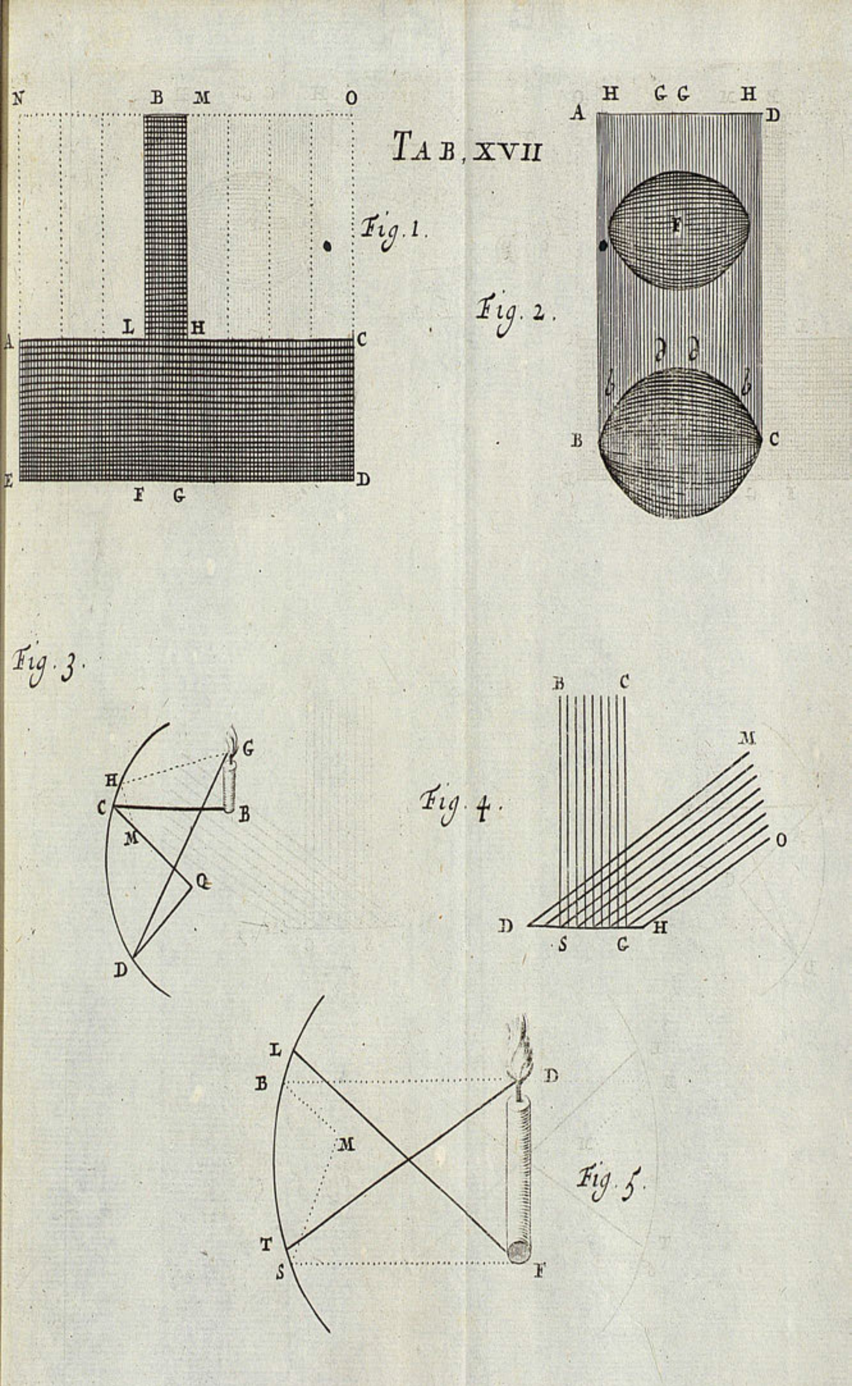

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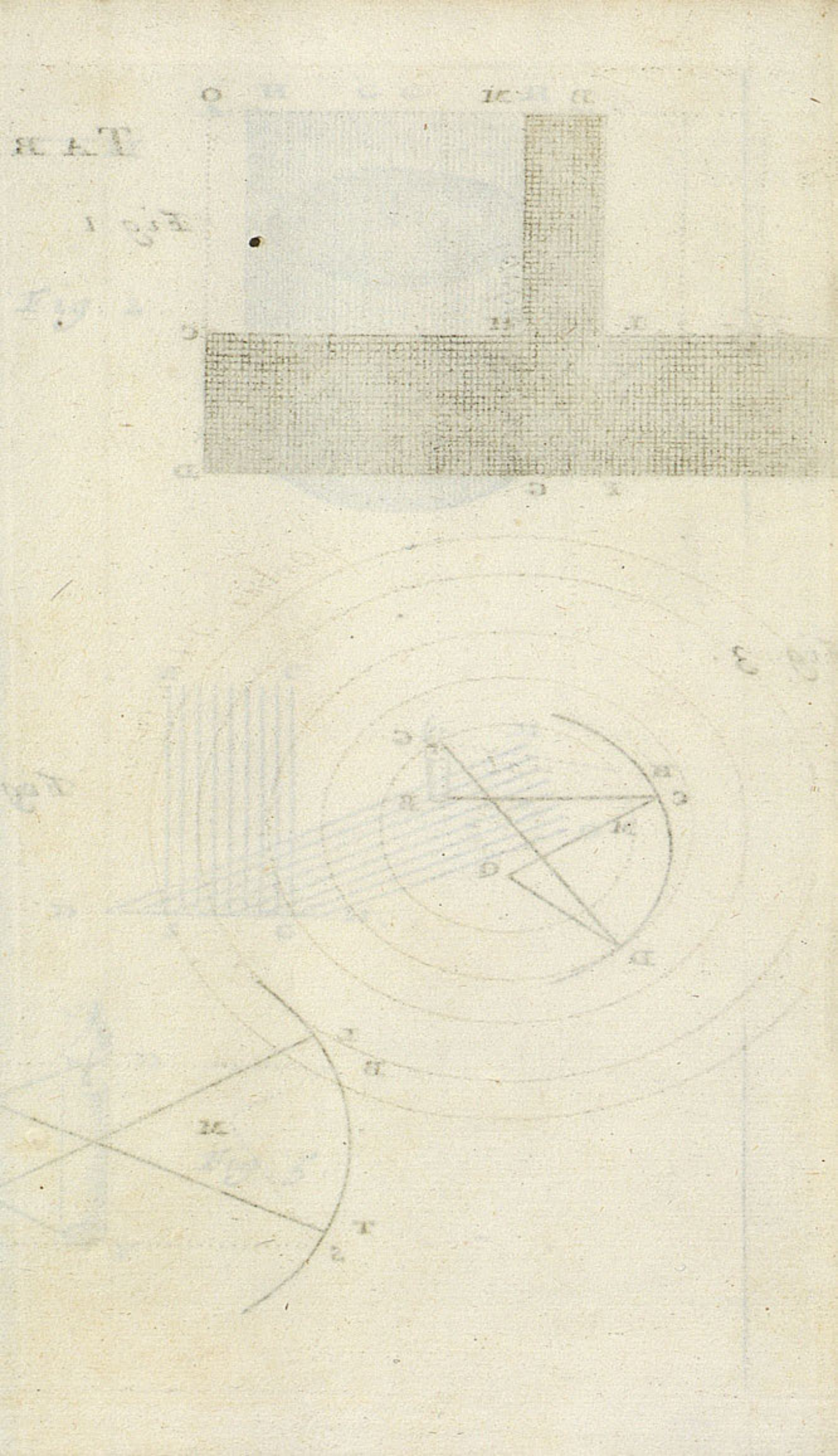


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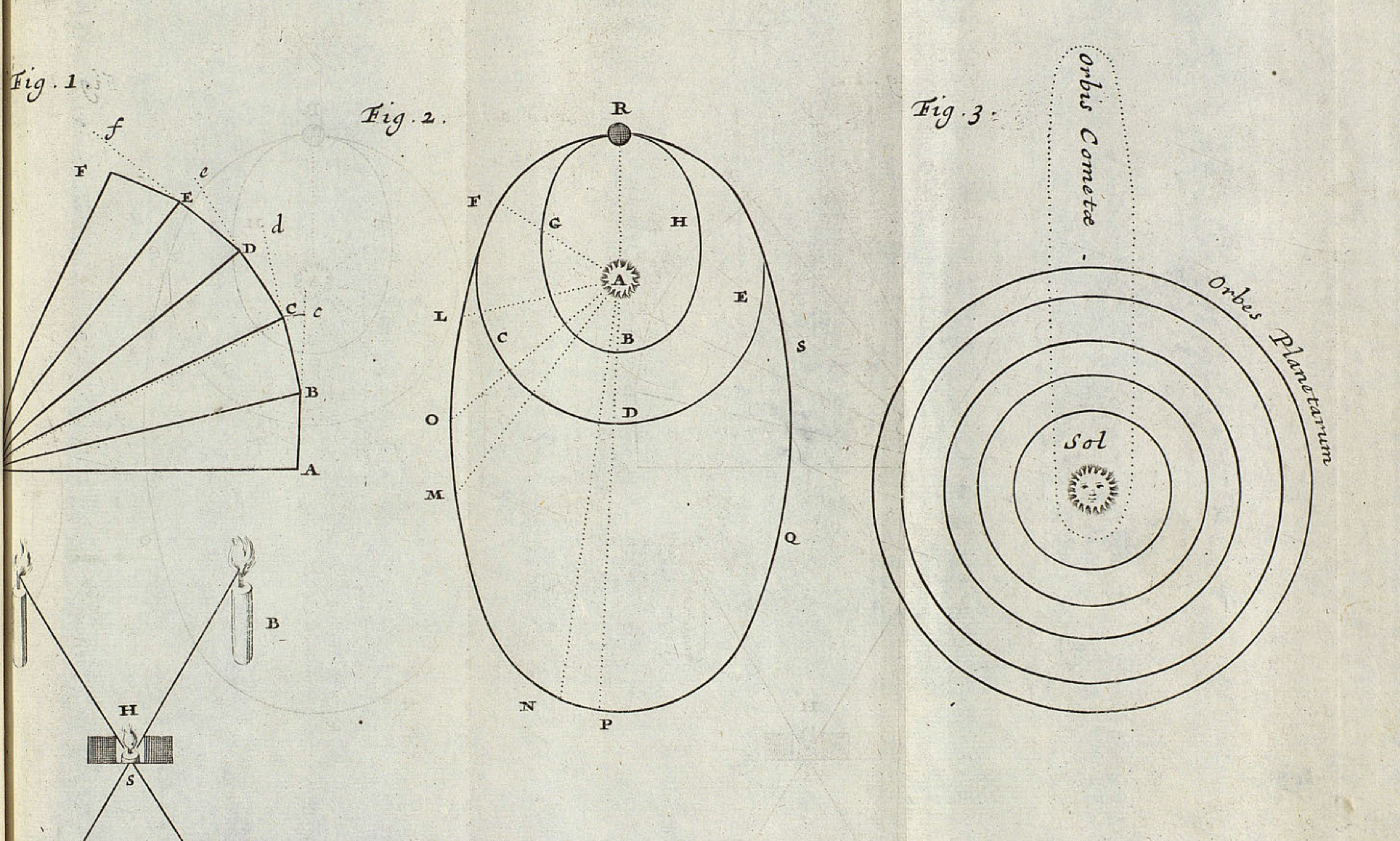


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Orbis Cometæ
Orbes Planetarum
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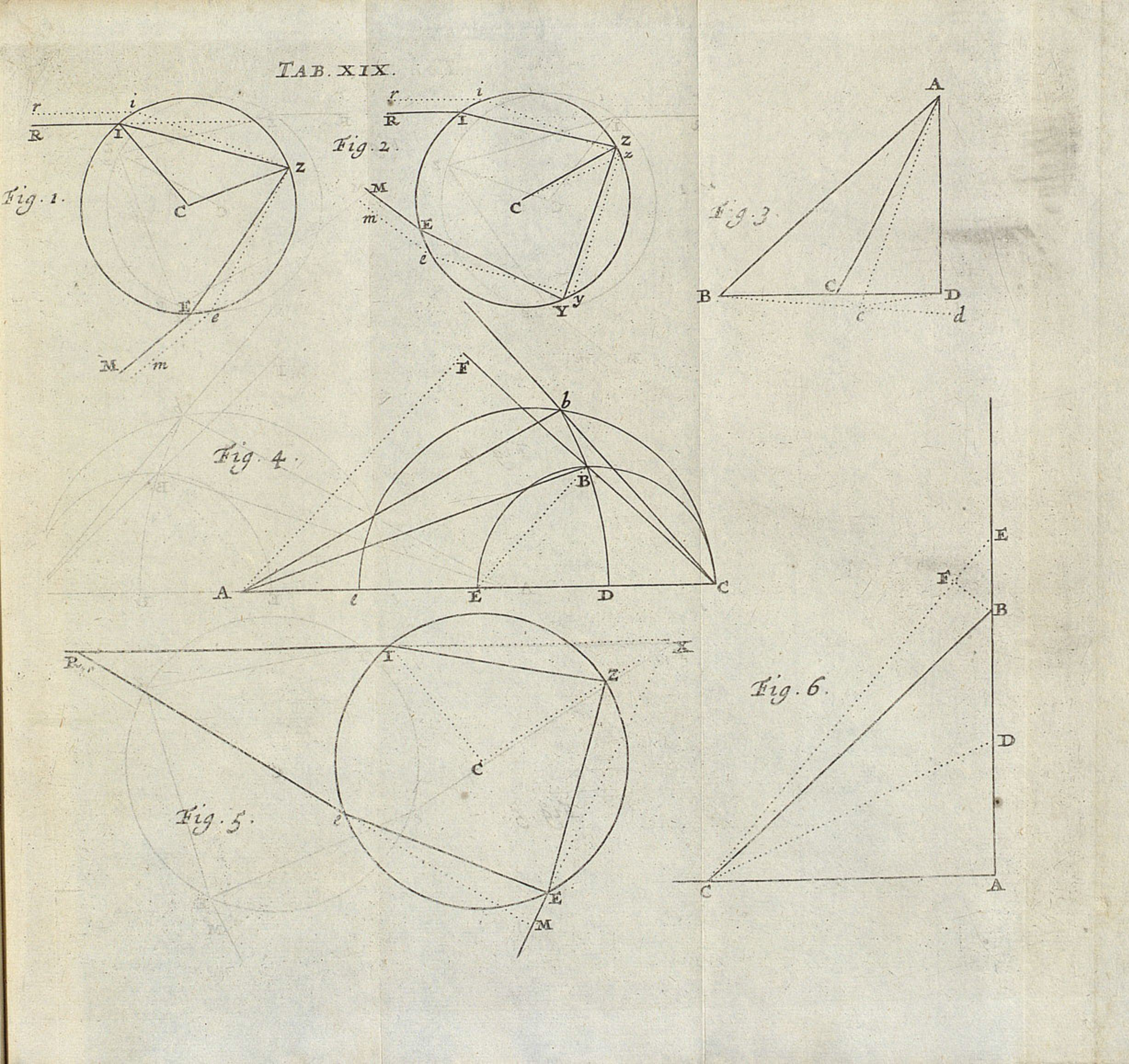
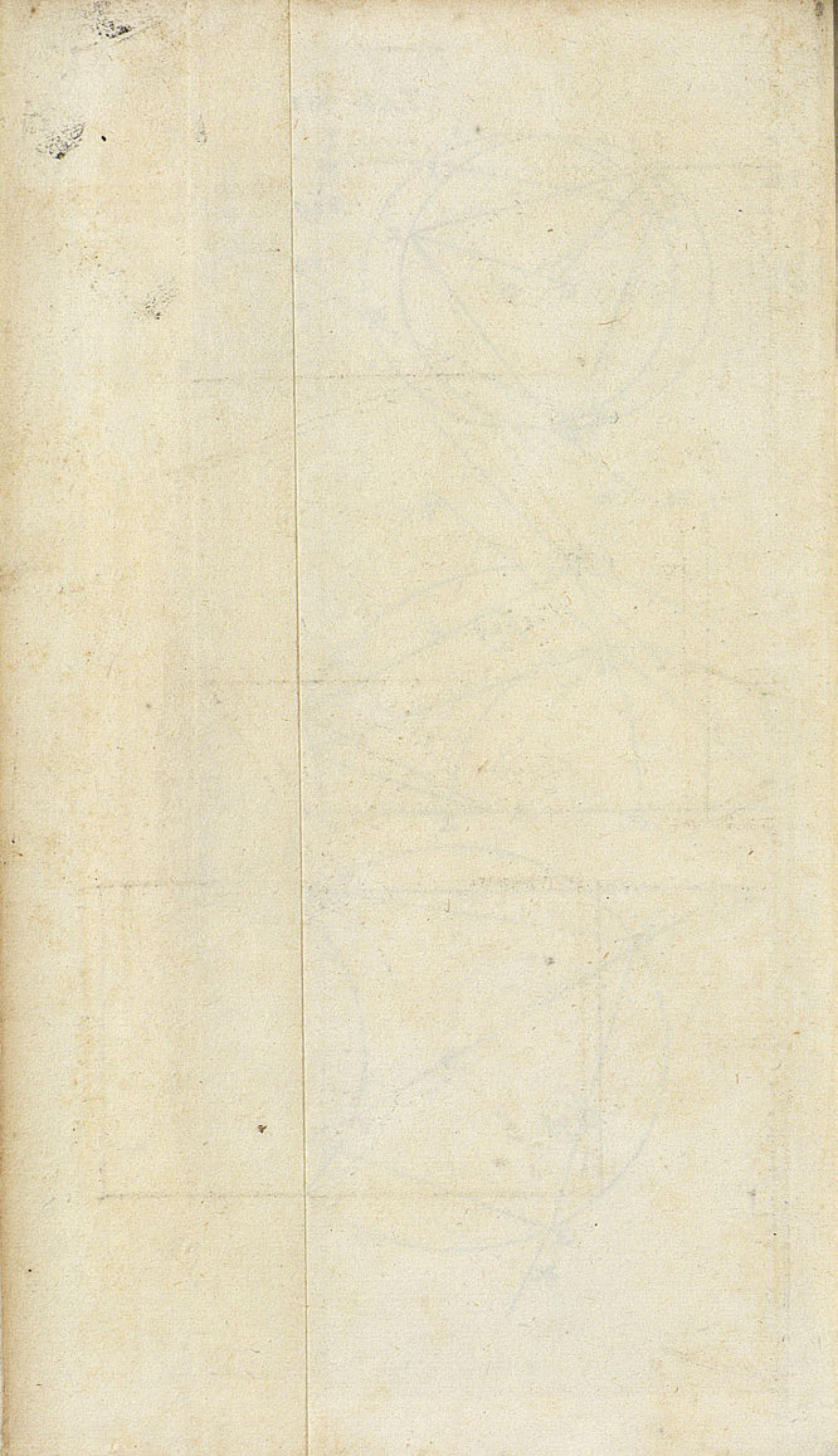
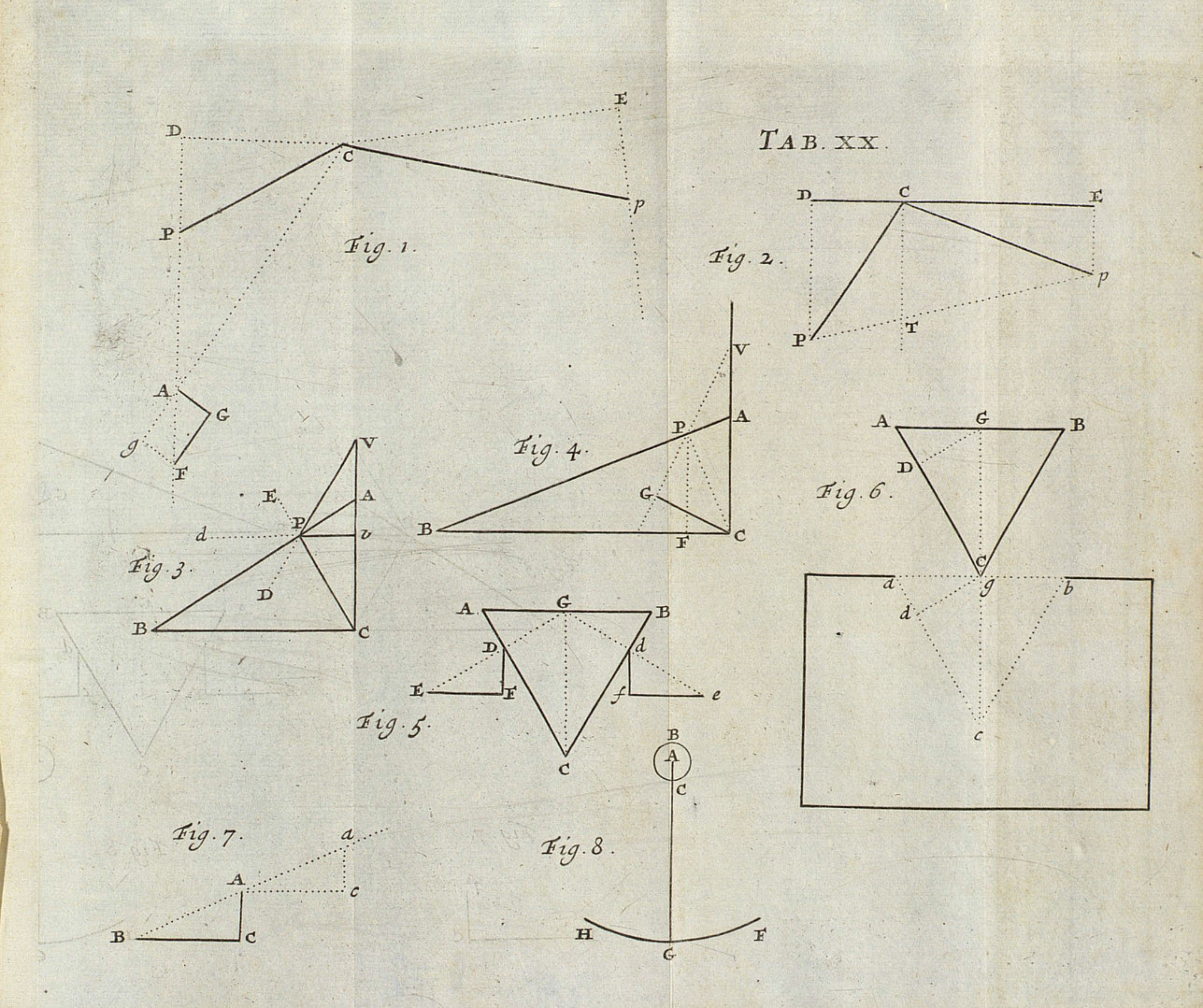
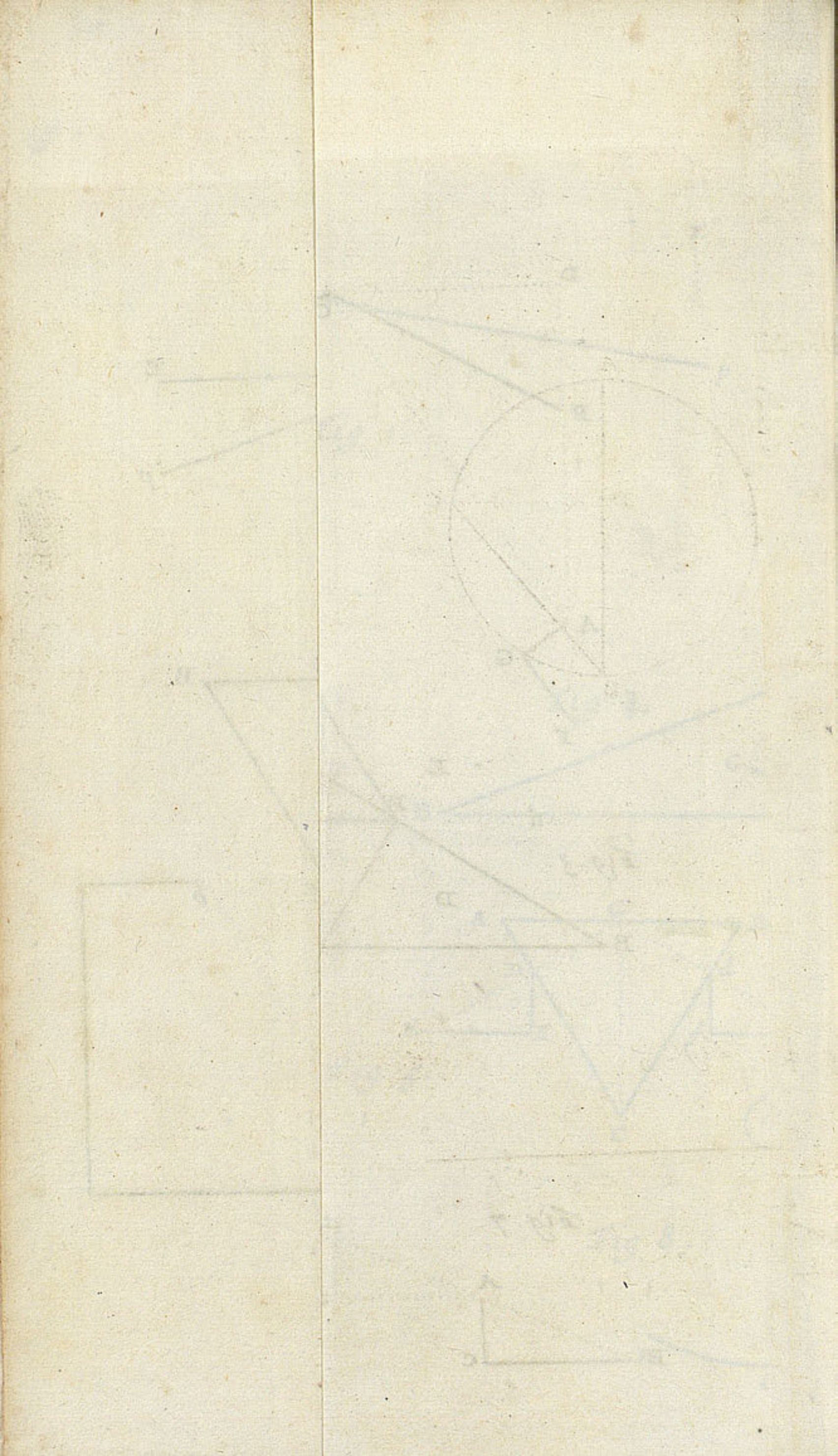


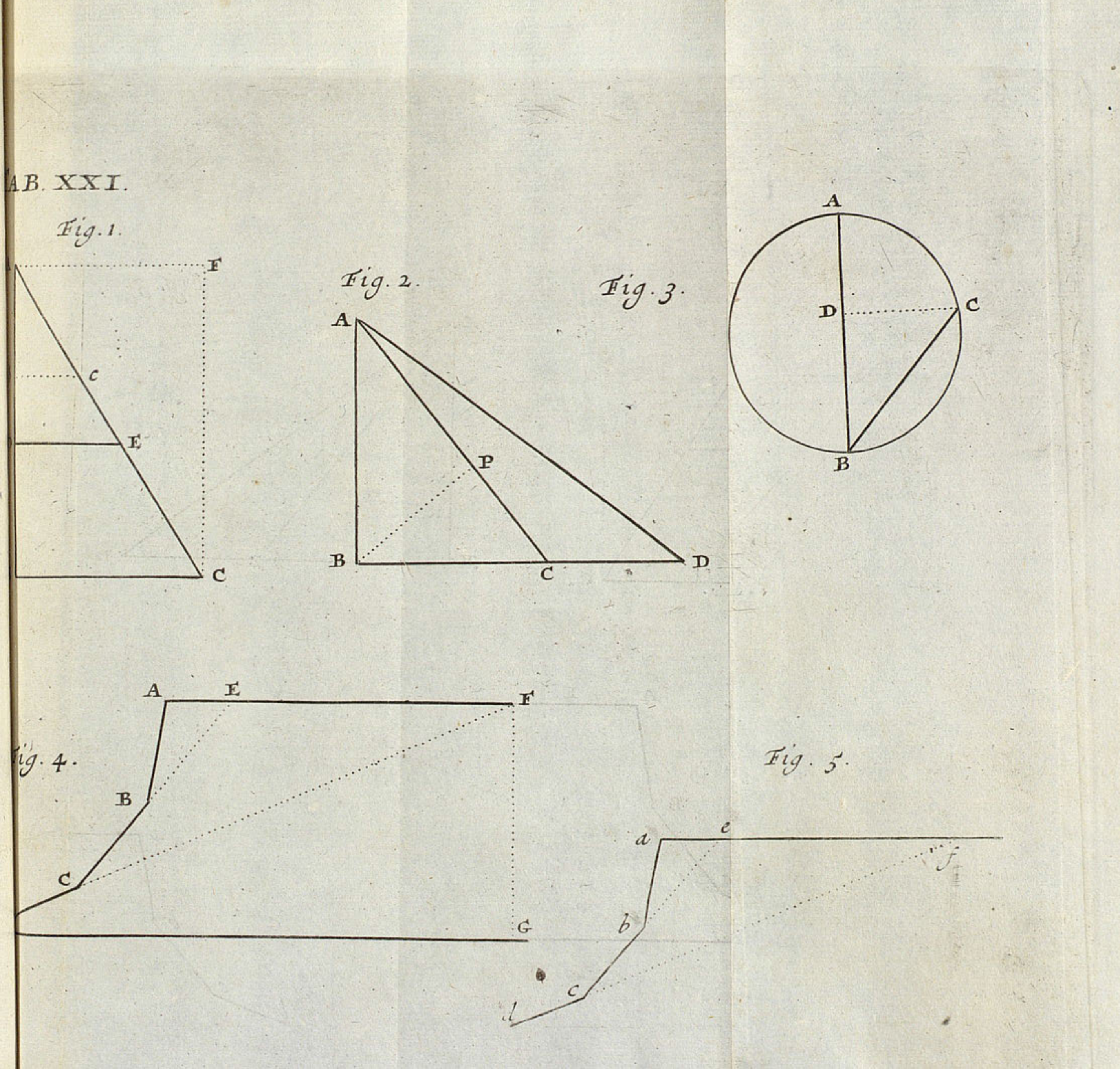
Fig. 1.
r
i
R
I
Z
C
E
e
M
m
Fig. 2.
r
i
R
I
Z
z
M
m
E
e
C
Y
y
Fig. 3
A
B
C
D
c
d
Fig. 4.
F
b
B
A
e
E
D
C
Fig. 5.
R
I
X
Z
C
e
E
M
Fig. 6.
E
F
B
D
C
A

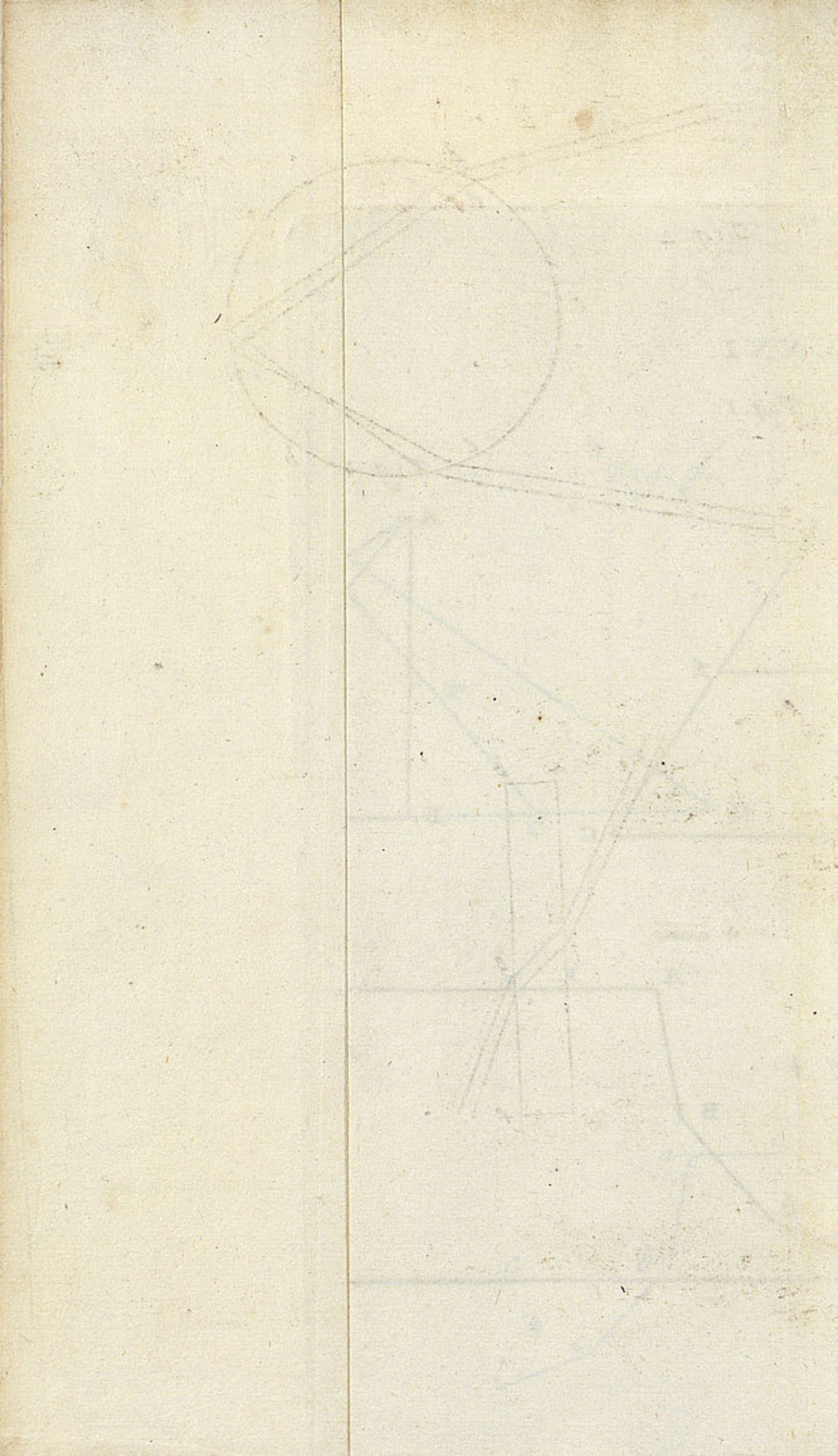



TAB. XX.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.



AB. XXI.





TAB. XXII.

Fig. 1.

a b d e d e c

Fig. 2.

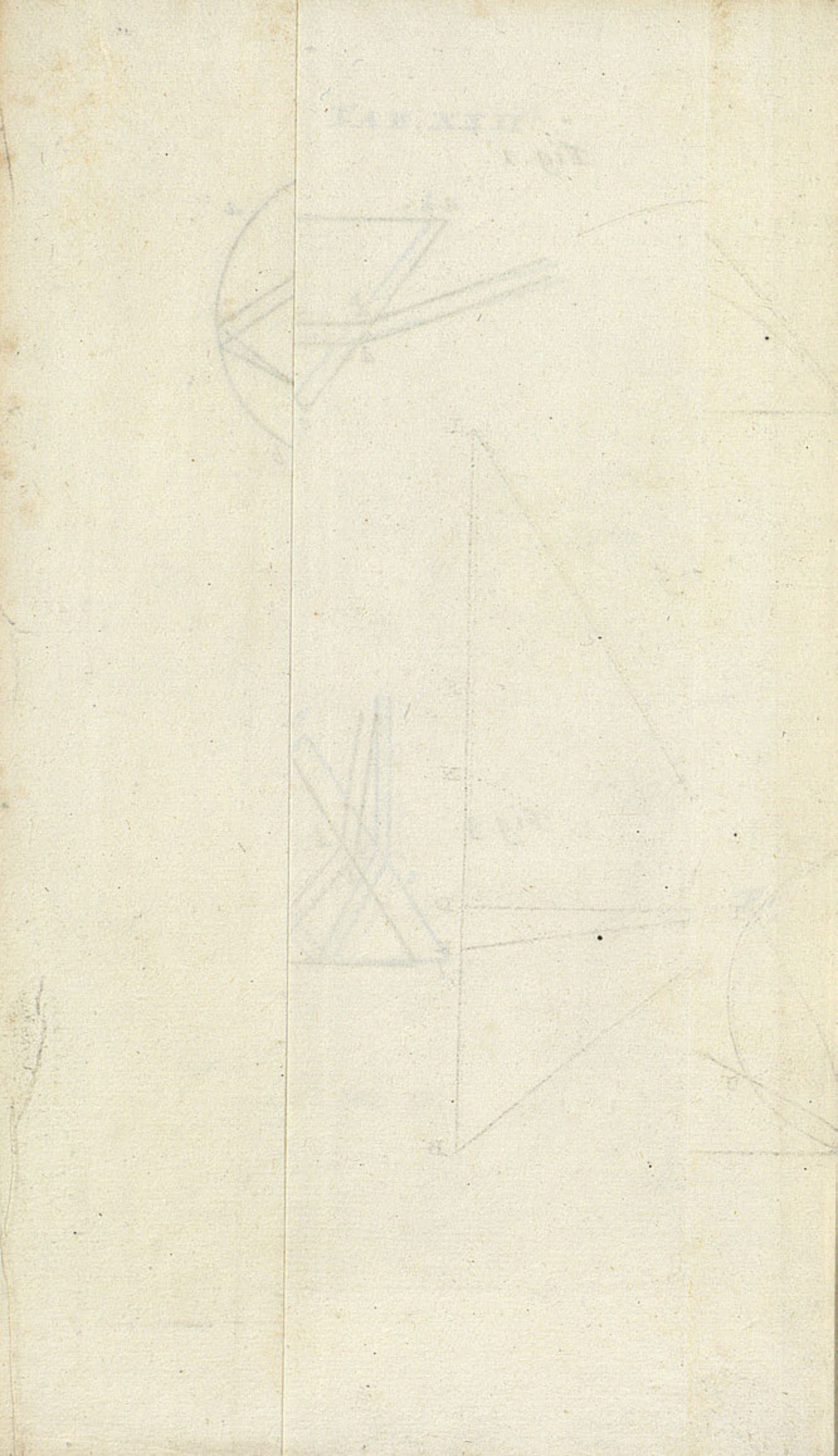
d d a c e b e

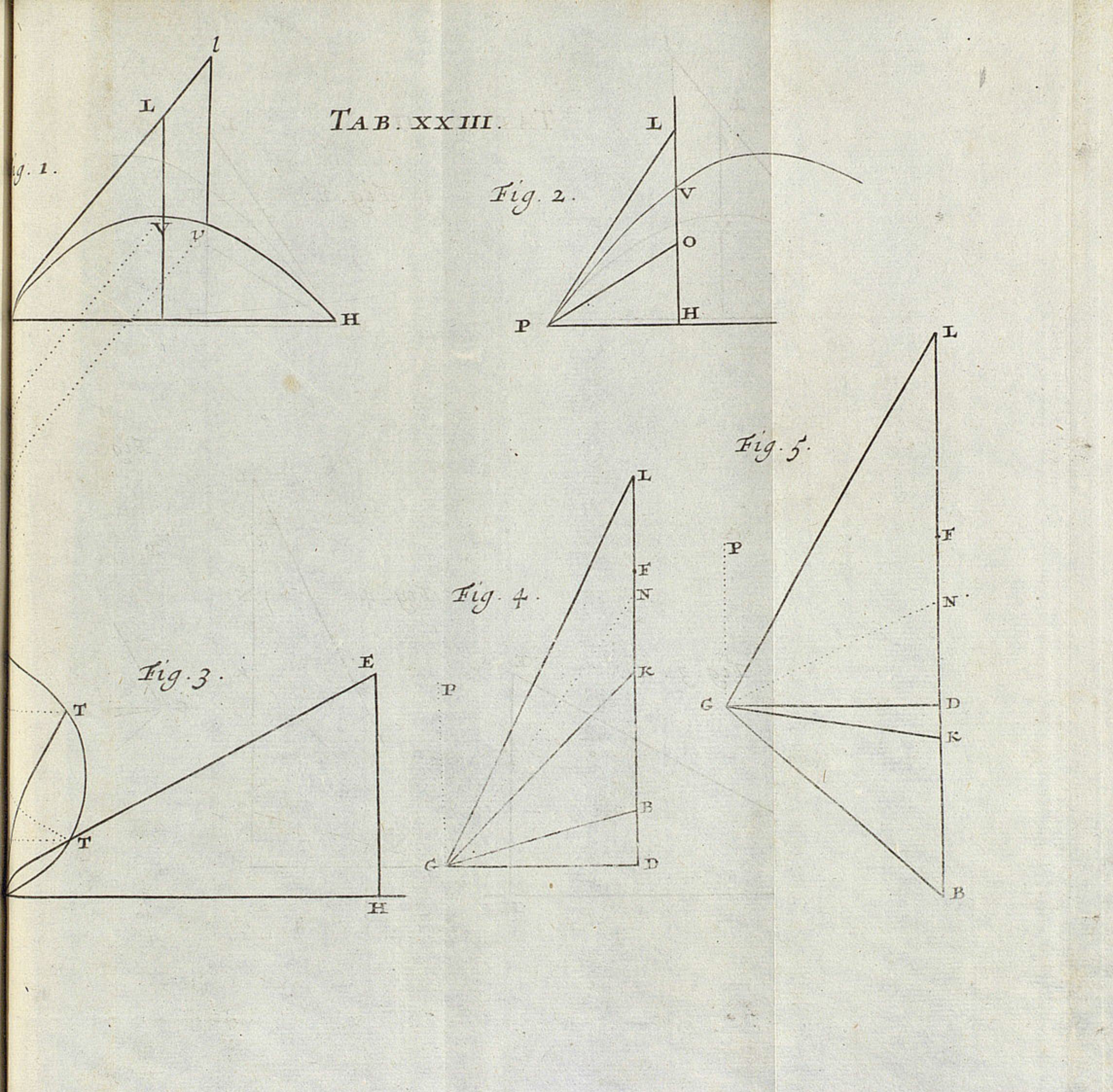
Fig. 3.

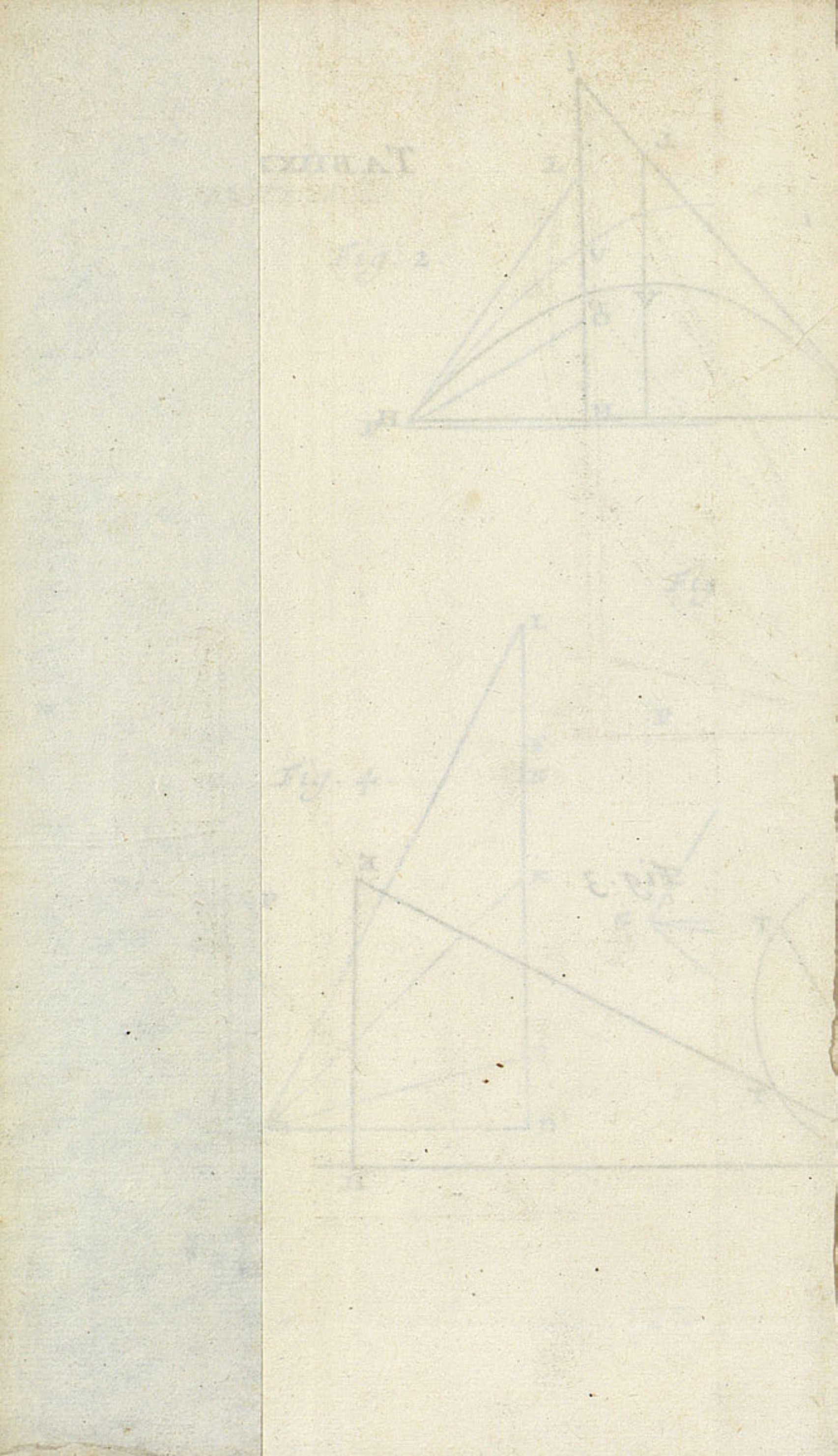
g d e d e l o

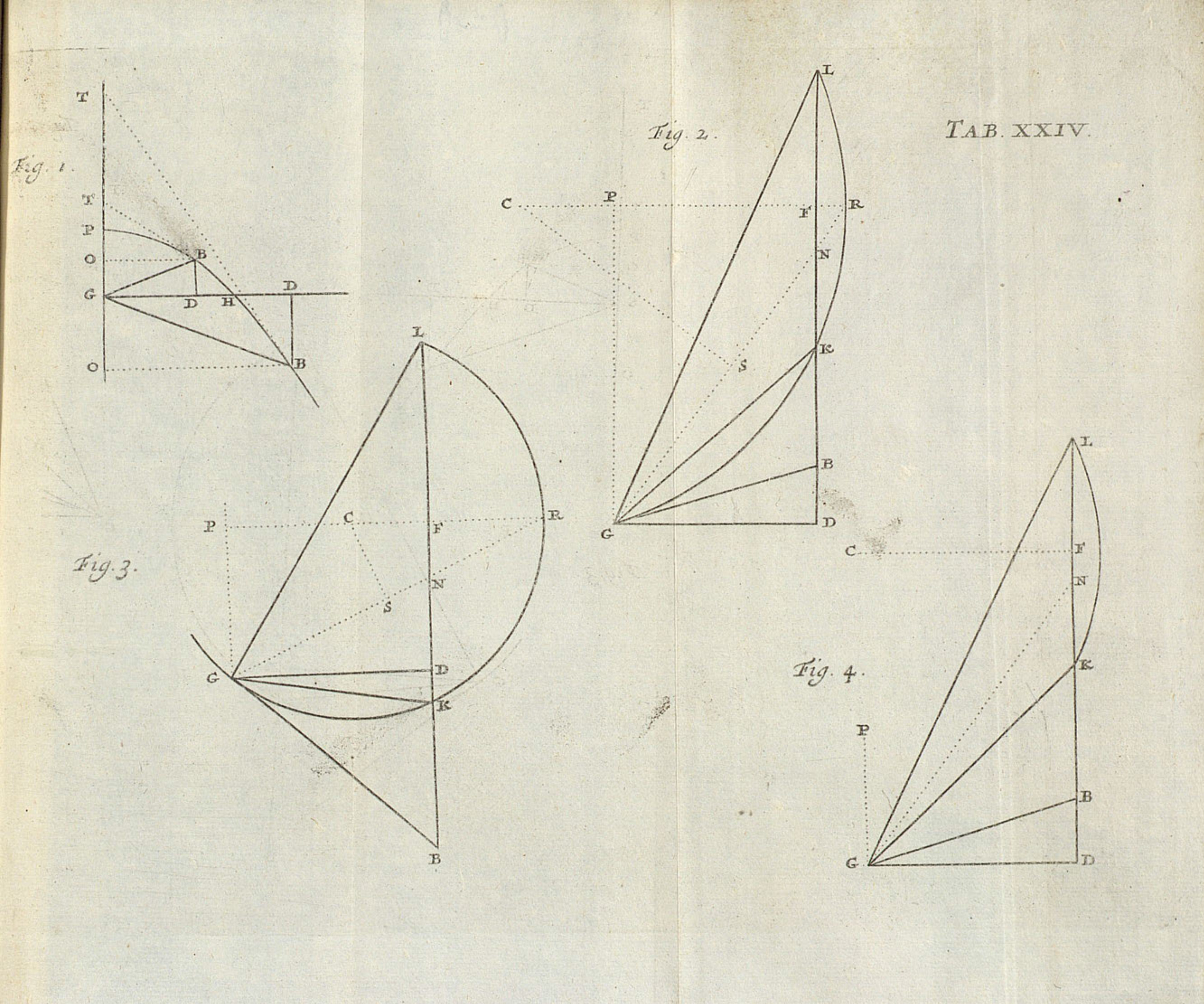
Fig. 4.

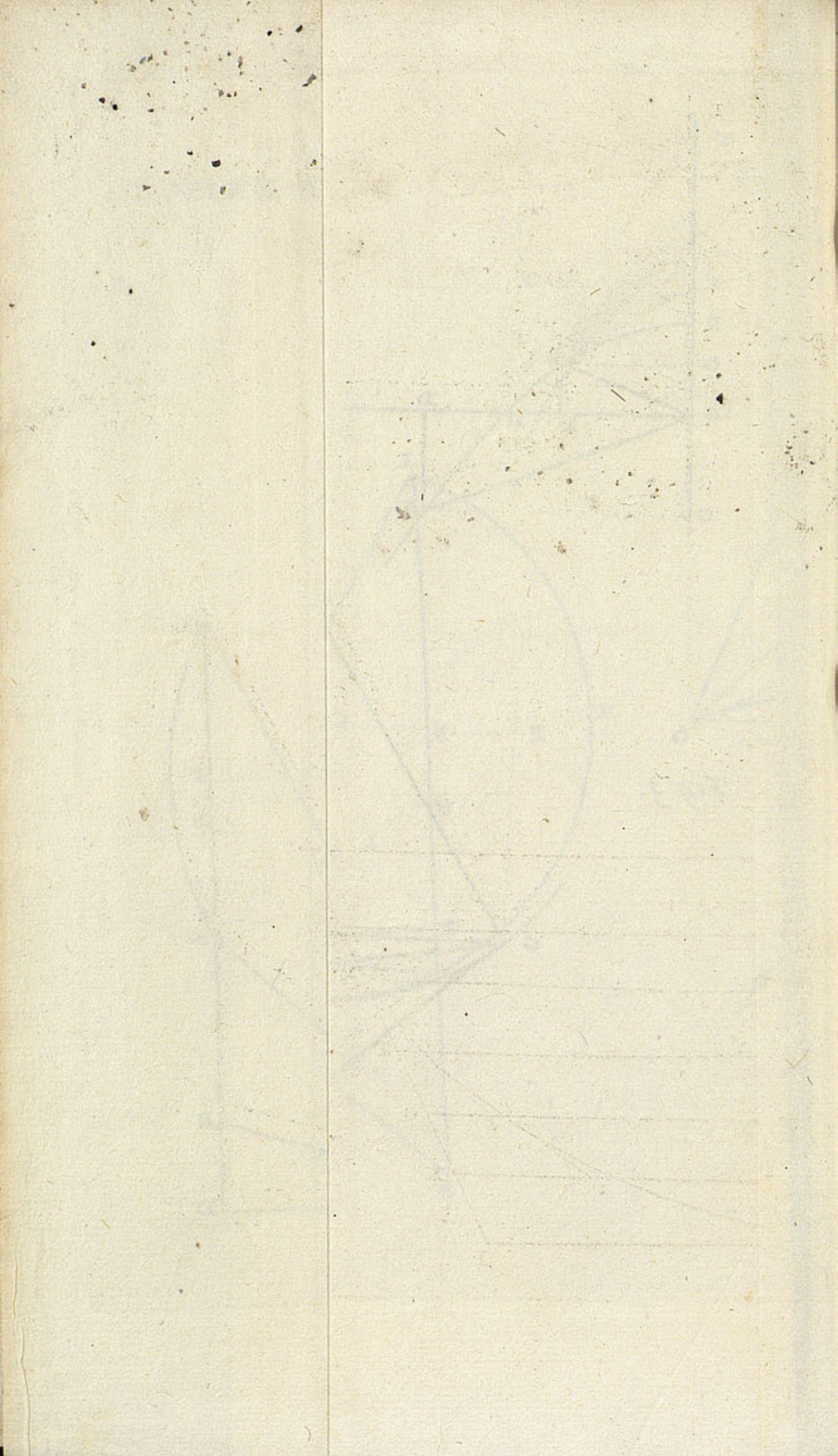
a b d d e e c f

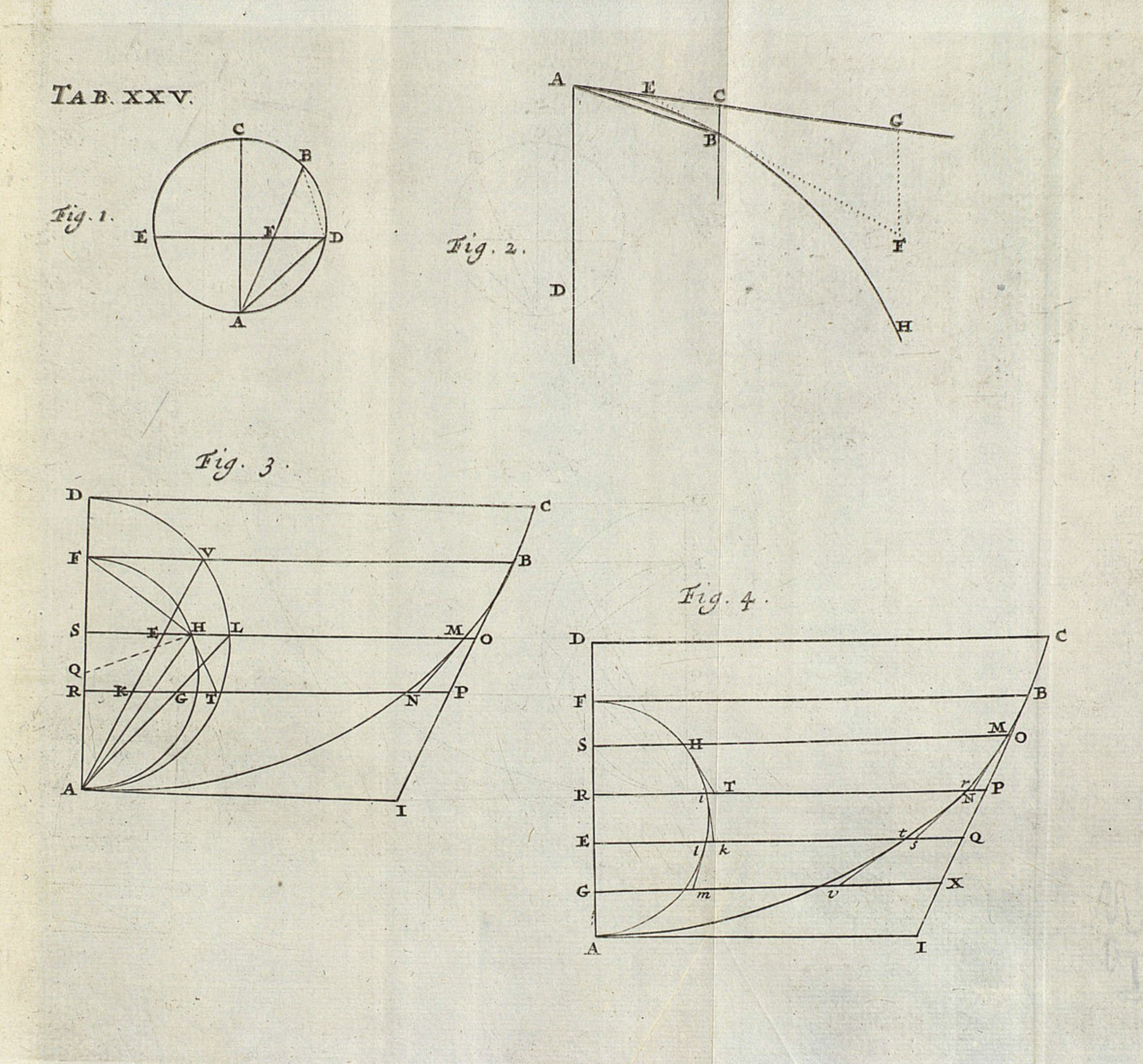


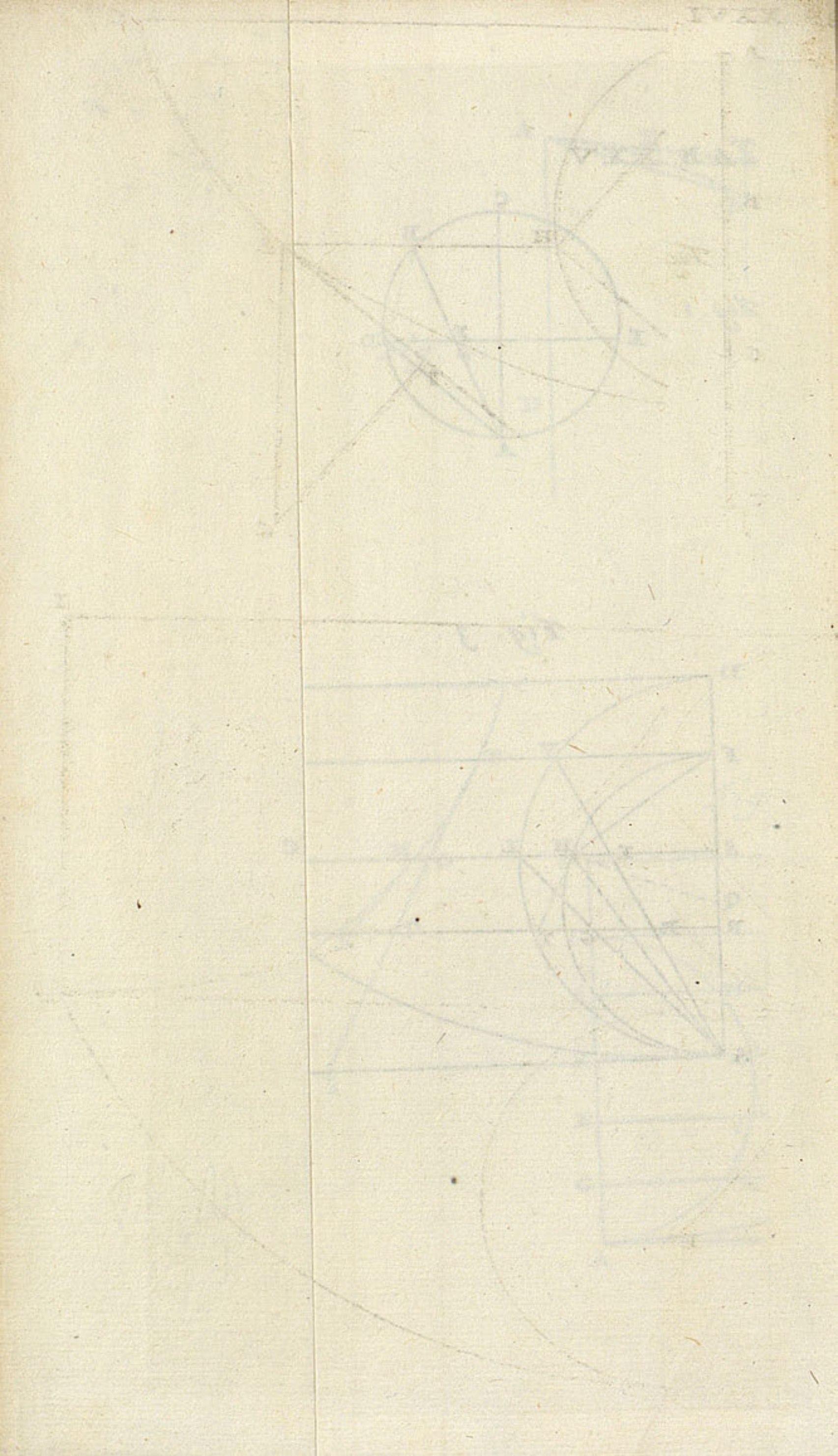

TAB. XXIII.
Fig. 1.
l
L
V
v
H
Fig. 2.
L
V
O
H
P
Fig. 3.
E
T
T
H
Fig. 4.
L
F
N
K
P
B
G
D
Fig. 5.
L
F
P
N
G
D
K
B

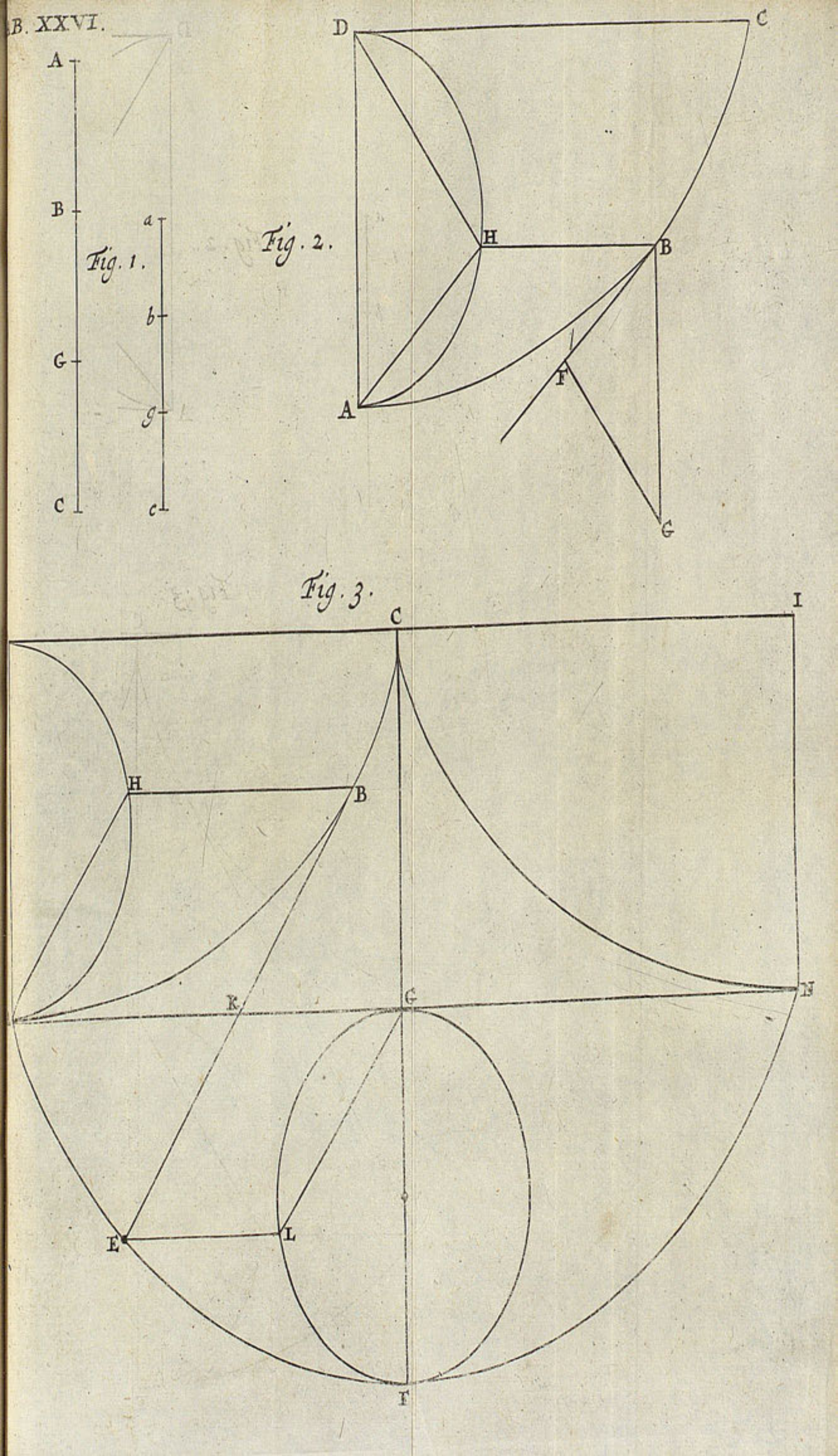


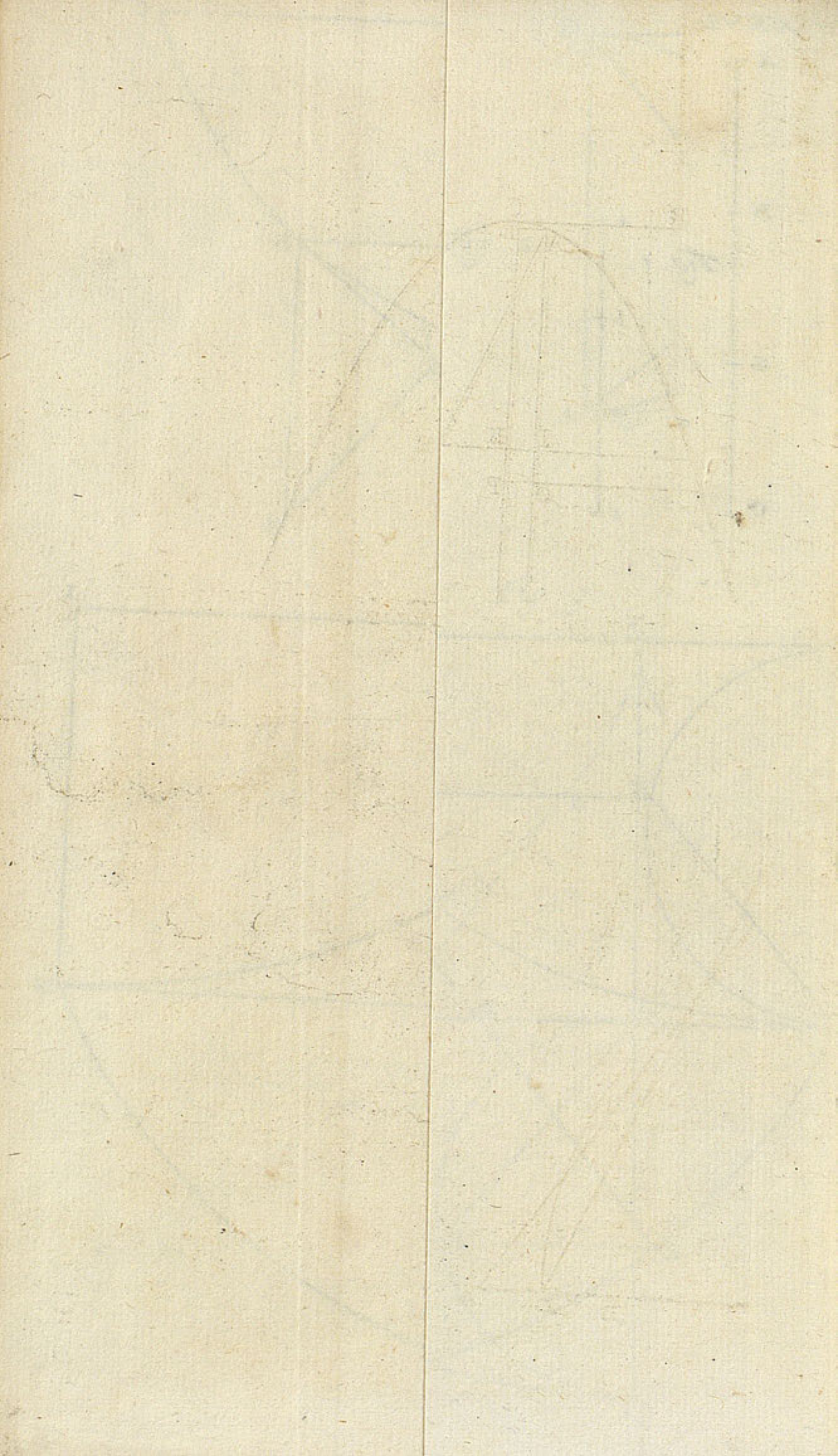

TAB. XXIV.
Fig. 1.
T
T
P
O
B
G
D
D
H
O
B
Fig. 2.
L
C
P
F
R
N
S
K
B
G
D
Fig. 3.
L
P
C
F
R
N
S
G
D
K
B
Fig. 4.
L
C
F
N
K
P
B
G
D

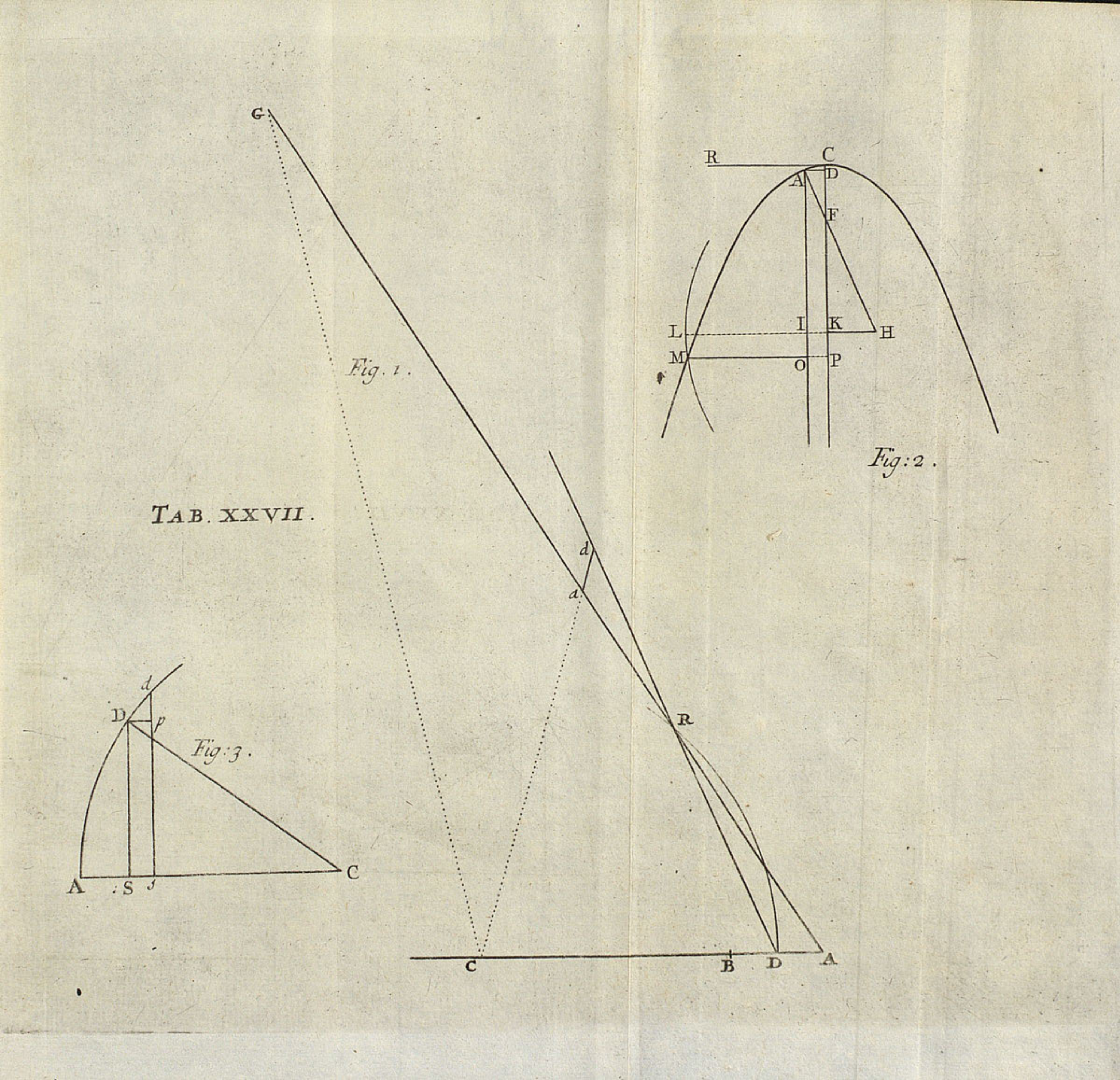



TAB. XXV.
Fig. 1.
C
B
E
F
D
A
Fig. 2.
A
E
C
G
B
F
D
H
Fig. 3.
D
C
F
V
B
S
E
H
L
M
O
Q
R
K
G
T
N
P
A
I
Fig. 4.
D
C
F
B
M
S
H
O
R
T
i
r
N
P
E
l
k
t
s
Q
G
m
v
X
A
I




A
B
G
C
a
b
g
c
Fig. 1.
D
C
H
B
A
F
G
Fig. 2.
Fig. 3.
C
I
H
B
K
G
N
E
L
F




TAB. XXVII.
Fig. 1.
G
d
a
R
C
B
D
A
Fig: 2.
R
C
A
D
F
L
I
K
H
M
O
P
Fig: 3.
d
D
p
A
S
s
C

